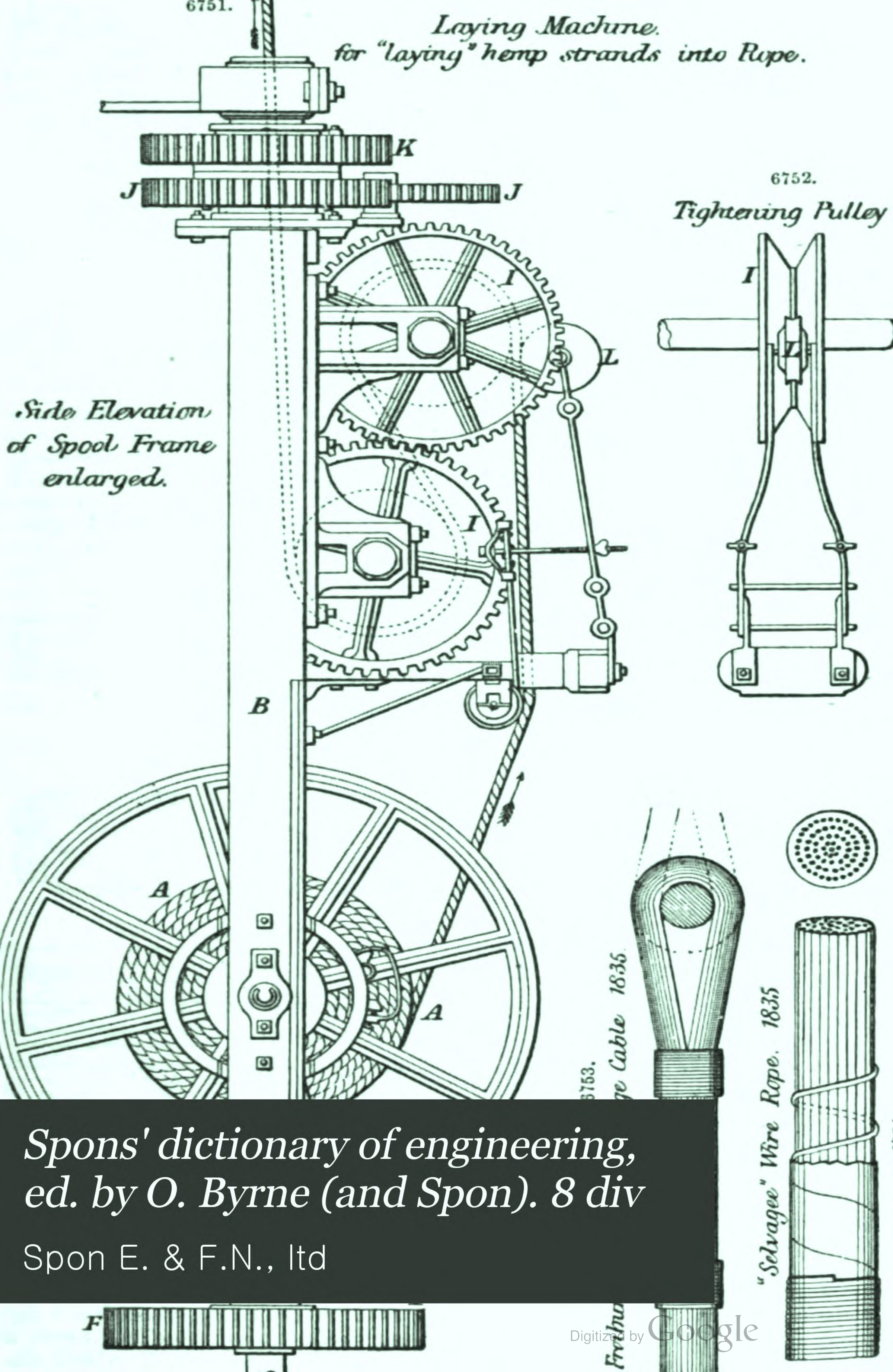


Spons' dictionary of engineering, ed. by O. Byrne (and Spon). 8 div

Spon E. & F.N., ltd

SPONS'

DICTIONARY OF ENGINEERING.

DIVISION VIII.

SPONS'

DICTIONARY OF ENGINEERING,

Civil, Mechanical, Military, and Naval;

WITH TECHNICAL TERMS

IN FRENCH, GERMAN, ITALIAN, AND SPANISH.

EDITED BY

BYRNE AND SPON.

DIVISION VIII.

LONDON;
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK; 446, BROOME STREET.
1874.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

PREFACE.

PREVIOUS to the publication of the present work, the want of a book of reference on Civil and Mechanical Engineering had long been experienced by the Engineer. A great deal of information of a useful kind had been recorded in the various Scientific Journals and Transactions of Engineering Societies, but it was given in a form not available for ready reference. The work so much needed is supplied, we trust, in this Dictionary of Engineering, written mainly by practical Engineers well acquainted with special branches of their profession, and whose names will be found in the List of Contributors.

Use has also been made of a large number of works devoted to Civil, Mechanical, Military, and Naval Engineering, and of the published writings of eminent Engineers.

Many subjects which ought perhaps to have a place in a complete work have been omitted, in the desire to confine the number of pages to something near the limit announced at the commencement; but we may be allowed to add that no other work on Engineering has been published which contains such a variety and amount of information on the same class of subjects in a collective form.

From the commencement of the work until August, 1872, the editorial department was conducted by Mr. Oliver Byrne, assisted by Mr. Ernest Spon; at that period Mr. Byrne ceased to be Editor, and the work has been completed under the direction of Mr. E. Spon.

Our thanks are specially due to G. G. André, Esq., C.E., for the careful attention bestowed on the subjects entrusted to him; and we also return our sincere thanks to the kind friends who have assisted in the compilation and revision of the various articles.

E. & F. N. SPON.

LIST OF CONTRIBUTORS.

Adriani, Dr.
André, Geo. G., Civil Engineer, M.S.E.
Anstruther, Major-General P.
Ardagh, J. C., R.E.
Atwool, Josiah.
Beck, W. H., Mechanical Engineer.
Bower, George, Gas Engineer.
Burgh, N. P., Marine Engineer, M.I.M.E., Assoc. Inst. C.E.
Byrne, Oliver.
Cargill, Thos., B.A., A.I.C.E., M.S.E.
Colburn, Zerah, C.E.
Coles, Capt. Cowper, P.
Conti, Lt.-Col., Royal Italian Engineers.
Dawnay, Archibald D., C.E.
Denison, Sir W., K.C.B., Col. R.E.
Don, Thos., Millwright.
Dunn, Thos., Mechanical Engineer.
Eckhold, C.
Edson, M. B., of New York.
Guthrie, C. T.
Hall, Henry, F.R.G.S., late War Dept. Surveyor.
Hann, E., Mining Engineer.
Hart, J. H. E., Civil Engineer, M.I.C.E.
Hurst, J. T., C.E.
Jauralde, C.E., Madrid.
Jeffcock, Parkin, Mining Engineer.
Kaulbach, E.
Lindner, Rudolph.
Moncrieff, Capt. C. C. Scott, R.E.
Müller, Moritz.
Napier, R. D.
Reid, W. F.
Richards, John, of Philadelphia, Mechanical Engineer.
Selwyn, Capt. Jaspar H., R.N.
Smith, Major-General M. W., C.B.
Soames, Peter, M.I.M.E., A.I.C.E.
Spence, Peter, F.C.S.
Spencer, A.
Spon, Ernest.
Stevenson, Graham.
Tweddell, R. H., Mechanical Engineer.
Wilson, Robert.

Among the able Authors from whose writings valuable information has been selected, the following may be mentioned ;—

Addenbrooke, George.
Allan, Alex.
Anderson, Dr. John.
Armstrong, Sir William.
Atkinson, J. J.

Baker, W. Proctor.
Beardmore, N.
Bell, I. Lowthian.
Benson, Martin.
Bloxam, C. L.
Box, Thomas.
Briggs, Robert.
Brown, Henry T.
Browne, W. R.
Burgoyne, Major-Gen. Sir John H.
Burnell, G. R.
Carr, Thomas.
Chapman, Ernest T.
Clark, Latimer.
Clift, J. E.
Cochrane, Charles.
Cochrane, W.
Conrad, Chevalier.
Coulthard, Hiram C.
Cowper, E. A.

Craig, W. G.
Culley, R. S.

Daglish, G. H.
Darcy, M.
D'Aubuisson de Voisins, J. F.
Dieudonné, C.
Douglass, James N.
Dru, M.

Eichhorn, Jacob.
Elliot, George.

Fairbairn, Sir William.
Fernie, John.
Forsyth, W.
Fothergill, B.
Fowler, John.
Francis, J. B.

Gale, James M.
Gaudard, Jules.
Greenwood, Thomas.
Greig, David.
Grubb, Thomas.
Grubhard, A.

Hague, James D.
Halsted, Admiral E. Pellew.
Hamilton, Colonel, R.E.
Harrison, T. E.
Henderson, D. M.
Henderson, James.
Hewitt, Abram S.
Hick, John.
Higgin, George.
Holley, Alex. L.

Imray, John.
Inglis, William.

Jenkin, Fleeming.
Joly, M.

King, Clarence.
Kingsbury, W. F.
Kirkaldy, David.
Kirkwood, James P.
Kirtley, William.
Knight, Cameron.

Low, George.
Lyall, Sir Charles.

Mallet, Robert.
Martin, Henry.
Menalaus, William.
Miller, Daniel.
Morin, General A.

Naquet, A.
Neville, John.
Newland, J.
Newton, A.
Noble, Captain.
Nystrom, John W.

Ott, A.
Overman, Frederick.

Paget, Arthur.
Paul, Dr. B. H.
Peclet, E.
Percy, Dr. John.
Périssé, Sylvain.
Phillips, John Arthur.
Platt, John.
Poncelet, J. V.
Porter, C. G.
Prony, R. de.

Ramsbottom, John.
Rankine, W. J. M.
Raymond, R. W.
Reid, P. S.
Roebling, J. A.
Rose, H.
Roy, Edmond.

Sabine, R.
Samuelson, Alex.
Samuelson, Bernhard.
Sang, E.
Scott, G. L.
Scott Russell, John.
Scratchley, P. H.
Shelley, Charles P. B.
Slate, Archibald.
Smith, Thomas.
Sonnet, H.
Sopwith, Thomas, jun.
Stanley, F. W.
Stoney, B. B.
Swindell, J. G.
Symons, G. J.

Thornycroft, Thomas.
Tinmouth, Nicholas.
Towne, H. R.
Truran, William.

Unwin, W. Cawthorn.

Vuillemin, L.

Waller, W.
Wanklyn, Dr.
Williams, Charles Wye.
Williams, J. B.
Wood, Nicholas.

pipes would create a partial vacuum in that part of its motor cylinder; but then the atmosphere pressing on the surface of the water in the cistern would at once open the valve and admit as much water from the cistern as required to restore the necessary equilibrium. Other appliances for signalling a defect and instantly remedying it have been provided; but we shall not describe them here.

By this system, the force developed by the motor may be transmitted to the pump without any other loss than that due to the friction of the water, which for a depth of a thousand feet will usually be less than 2 per cent. of the total force required to raise the water. It is applicable to water as well as to steam power, and the pumps being double-acting, no portion of the power of the water-wheel is lost. The pressure-pipes are fixed parallel to each other against the sides of the shaft, or upon the floor of a level, so that the space occupied by them is practically nothing. When used in the place of flat rods, that is, when carried horizontally from the engine-house or water-wheel to the shaft, they may be laid underground so as not to obstruct surface operations. One great advantage possessed by this system is the facility it affords for changing the direction. Provided sharp angles are avoided, the pressure-pipes may be carried along in all manner of directions, as occasion and locality may require, without any appreciable loss of power.

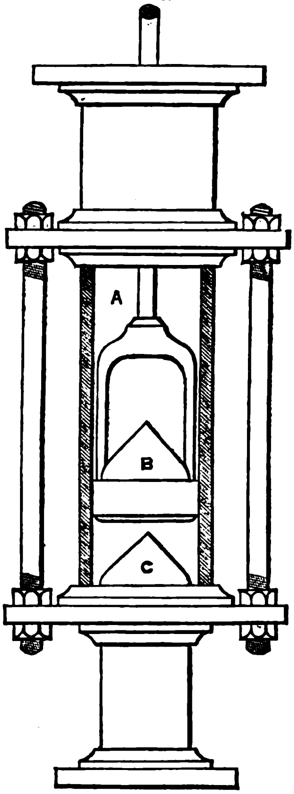
Pumps for Surface-draining.—The requirements of surface-draining, and the conditions under which a pump applied to that purpose has to work, are altogether different from those which we have been considering. In mines a comparatively small quantity of water has to be lifted to a great height, and the motor is, in most cases, necessarily situate a long distance from the pump. For surface work, such, for example, as draining a marsh, a large quantity of water is required to be lifted to a small height, and the motor may be placed close to the machinery to be driven. Generally the motor will be steam; for it is rarely possible to obtain water-power in a convenient situation. In Holland wind is frequently employed for this purpose, but the variable character of this motor renders it unsuitable for pumping operations. It may, however, often be used as an auxiliary with great advantage. The kind of pump best suited for surface drainage is, in general, the centrifugal pump. The nature of this pump renders it peculiarly well adapted for this kind of work. It is exceedingly simple in construction, is easily erected, and requires no massive foundations. The absence of valves is a great advantage, as small pieces of wood, weeds, and other small floating substances, may be passed without choking the pump. An experiment was made some time ago with one of Appold's 12-in. pumps by throwing in all at once about half a gallon of nut-galls when working at full speed. They all passed through without one being broken. Also when the height of lift is small, a very large quantity of water may be raised a minute by a centrifugal pump, a condition usually imposed by the nature of the work, and which this pump is therefore capable of fulfilling. We have described and illustrated some of the best models under Hydraulic Machines, and hence it will be unnecessary to do more than refer to them here. In many cases, Murray's chain-pump may be applied to the purpose of surface drainage with advantage, especially when the area to be drained is small. It will be for the engineer to determine which of these kinds is the more suitable to the requirements of the case under his consideration.

Pumps for Water-supply.—The requirements of this case are—a large quantity of water to be raised to a considerable height, and a steady, continuous supply, requirements which neither the centrifugal nor the chain pump is capable of satisfactorily fulfilling. Reciprocating pumps are exclusively used for this purpose. Whether, however, the lifting or the forcing variety is the more suitable seems still to be an open question, judging from the want of uniformity in the practice of engineers. We have shown that whenever a considerable height of lift and a continuous working are conditions to be fulfilled, the force-pump possesses great advantages over the lift; and it is satisfactory to see that the former variety is gradually coming into favour. No particular construction can be recommended for this case, as a great deal must depend on local circumstances. For a small supply an arrangement of Hayward Tyler and Co.'s Universal pump has been found to work very satisfactorily. It has been used at the Slough Water-works, and also, as an auxiliary, at the Tottenham Water-works.

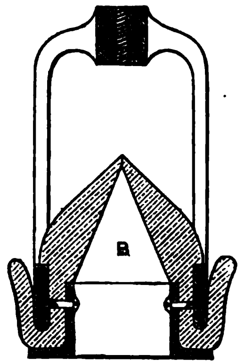
Pumps for Raising particular Liquids.—We have spoken of the corrosive properties of mine water, and the necessity of lining the working barrel and other working parts with brass, to enable them to withstand the corrosive action. This precaution is, however, insufficient in many cases where liquids of a particular nature have to be raised. Thus in chemical works pumps are required to raise strong acids and various other substances which would speedily destroy the working parts if constructed of ordinary materials. In paper-mills they are needed to raise the paper-pulp and bleachers; in breweries, for raising the hot wort; in gasworks, for pumping ammoniacal liquor and tar; in tan-yards, for pumping tan liquor; and also in town drainage works, for raising the sewage. The only kind of pumps suitable for these operations are the reciprocating kind, and of these the forcing variety is the best adapted for sewage, and, generally, the lifting variety for the other purposes mentioned. The fittings of pumps to be applied to any of these purposes should be of gun-metal. Cast-iron clacks are frequently used for pumping ammonia water; but generally gun-metal should be adopted. In chemical works it is often necessary to employ india-rubber instead of metal for the valves. In Fig. 6420 we illustrate a pump specially designed for these purposes, having india-rubber valves and a glass cylinder. The design and construction of this pump, which is known as Perreaux's, are excellent. The working barrel A is made from the best plate glass bored out by machinery and polished. The bucket-valve B and the foot-valve C, shown in section in Figs. 6421, 6422, are of india-rubber, and the elasticity of the material is relied upon to close them. We are not aware of any experiments made to ascertain the amount of slip through these valves, but the principles we laid down in the former part of this article would lead us to expect very little. The mode of fixing these valves is so clearly shown in the figures that description is unnecessary; we cannot, however, refrain from expressing our admiration of the very excellent nature of this mode, which is alike creditable to the designer and the constructor. The glass barrels are mounted in cast-iron suction-pipe and rising-main, with wrought-iron stretcher-

rods and nuts, as shown in Fig. 6420. The valves may be mounted in brass, lead, or gun-metal, as required.

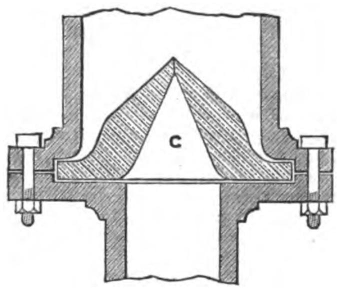
6420.



6421.



6422.



In raising hot liquids, such as the wort in breweries, suction cannot be employed by reason of the impossibility of creating a vacuum in consequence of the evolution of steam from the heated liquid. In such cases, therefore, the pump must be placed on a sufficiently low level to allow the liquid to enter by the force of its own gravity. When it is required to raise liquids of such a consistency as to be incapable of a rapid flow, as tar, for example, the motion of the pump should be slow, and the height of the suction should be reduced as much as possible. In such cases, the pipes and working barrel should never be of small diameter, and the valves should have a higher lift than is requisite for water. Also all contractions of the passages and changes of direction should be avoided, as they greatly impede the flow of thick liquids. These remarks apply, though in a less degree, to town sewage.

Pumps for Emptying Docks.—The requirements of this case are similar to those of surface drainage, and therefore the same pumps may be applied to this purpose. It should be remarked, however, that the nature of the chain-pump renders it peculiarly suitable to the work of emptying a dock.

Contractors' Pumps.—The chief purposes to which a contractor's pump is applied, are the removal of water from cuttings and other excavations, and the emptying of coffer-dams. The nature of the work, and the conditions under which it has to be executed, are such that a pump which is to be applied to these purposes must be simple in construction, capable of bearing rough usage, easily repaired when out of order, of such a nature that it may be readily erected in any locality, and as readily removed when circumstances require it, capable of raising a considerable quantity of water to a small height, and need but little attention. The whole of these requirements are fulfilled by the chain-pump, and accordingly we find this pump generally adopted. Of reciprocating pumps, Hayward Tyler and Co.'s Universal pump fulfils the above requirements, with the exception, perhaps, of that one which requires it to be capable of easy repair. This pump has been used on several engineering works recently, and appears to have given entire satisfaction. One advantage possessed by this pump is, that it may take its steam from a portable engine that is employed for other purposes, such, for instance, as sawing.

Bilge-pumps.—Bilge-pumps are the pumps used on board ships to remove the bilge-water, that is, the water which lies upon the bilge or bottom of the vessel. In their simplest form they consist of a pump having a staff or rod 7 or 8 ft. long, with a bar of wood to which the leather is nailed, and which serves instead of a box. This staff is worked by men who pull it up and down with a rope fastened to the middle of it. Bilge-pumps as now used in all but the smallest vessels, have all the improvements that of late years have been effected in this kind of machinery. Usually they are

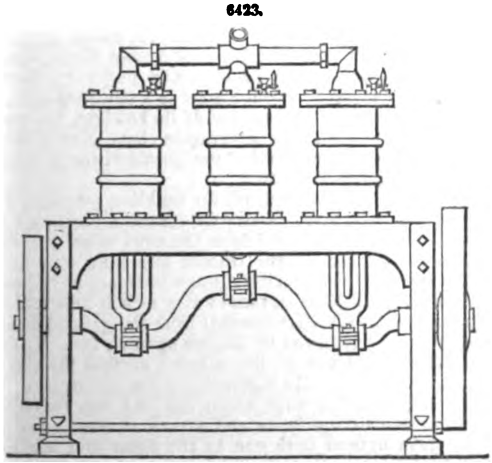
force-pumps, and in steam-ships they are worked by the engine. In such cases they are capable of raising a large quantity of water at a stroke. As they differ in no essential particular from the pumps we have already described, it will not be necessary to describe them here. Among the best designed and constructed of this class of pumps are those manufactured by Watt and Co. Centrifugal pumps have been successfully applied to this purpose.

Pumps for Supplying Hydraulic Machinery.—The purpose of this class of pumps is to force water into a receiver against the pressure exerted by a heavy weight, or by the elasticity of the opposing substance. The former case is that of Armstrong's accumulator, into which the water is forced by the engine against the pressure—often equal to 1500 ft. of water—exerted by the loaded ram, the latter that of Brahma's press, into which the water is forced against the pressure due to the elasticity of the substance compressed. The only kind of pump applicable to this case is the reciprocating, and of these only the forcing variety. There is nothing particular to note in pumps applied to these purposes, beyond the necessity of adapting their details to the work they have to perform. The chief requirement is that their several parts shall possess sufficient strength to withstand the pressure to which they will be subjected.

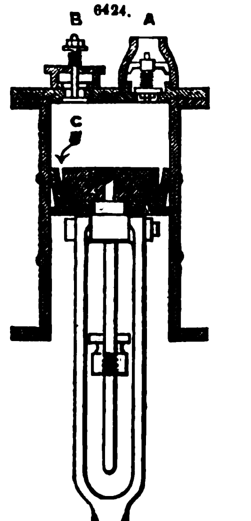
Feed-pumps.—These belong to the same class of pumps as the preceding. They are required to force water into a boiler against the pressure of the steam, and hence are subject to the same conditions as those for supplying hydraulic machinery. A certain degree of modification in the case of feed-pumps is due to the fact that they usually work against a lower pressure than the latter; but essentially the conditions are identical. The same kind and variety of pumps will therefore be requisite in this case. Feed-pumps have been fully treated of under Details of Engines, and we must refer the reader to that article for complete information on this subject.

Air-pumps.—Air-pumps are employed either to exhaust the air contained in a given space, or to compress the air contained in that space. The latter are of the nature of the forcing pumps employed for liquids; the former resemble the lifting pump. We have described and illustrated both kinds under Air-pump, Diving, and Details of Engines; in the latter of these articles the air-pump, as applied to steam-engines, being fully discussed. Recently, however, the compressing air pump has been applied to the setting of large iron columns in deep water, by expelling the water and mud from the bottom by means of compressed air instead of pumping it out of the top. The engineer of the new graving dock at Hog Island, Bombay Harbour, conceived the idea of setting the large columns, 6 ft. in diameter and 70 ft. in length, required for this work, in this way. To do this, however, an air-pump of great power and large volume was requisite. Such a pump was designed and supplied by Barnett and Foster, of London, and its use was attended with remarkable success. Fig. 6423 is a side elevation, and Fig. 6424 a section through one of the

6423.



6424.



cylinders of this large treble pump. These cylinders are 9 in. in diameter and 18 in. in length, the throw of the crank being 9 in., and the diameter of the latter 5 in. The leathering of the piston is on the principle adopted in hydraulic pumps, that is, it is so arranged that the pressure from within helps to tighten it. This arrangement is shown at C, Fig. 6424. The diameter of the inlet-valve B is $1\frac{1}{2}$ in., and that of the outlet-valve A 2 in. There is a copper cooling cistern around the outside of the pumps. This cistern is a cylinder of larger diameter than the pump-cylinder, the annular space between the two being filled with water to prevent the latter from becoming heated, and so to preserve the air within the pump from being rarefied. The three pump-cylinders are connected at the top, as shown in Fig. 6423, and hence the stream of air is continuous. On the top of each cylinder there is a lubricating cup.

The mode of applying this pump to the setting of the columns was as follows;—The several pieces were bolted together above water in a massive framework, and lowered to receive a fresh one till the first touched the bottom. The hood was then fitted into the top, and the interior of the

column put into communication with the air-pump. The water contained in the column was thus forced down and out at the bottom, the time required to clear out the whole of the contents being less than half an hour. Such was the force of the pressure developed, that the whole column would frequently lift fully 18 in., letting the mud out at the bottom. When cleared, the columns were entered, and filled up to a height of 5 or 6 ft. with hard cement, thus converting them into a solid mass at bottom. When it is added that the power requisite to work the air-pump was only 6-horse, the superiority of this mode of emptying columns over that usually adopted of pumping the water out of the top will be readily acknowledged.

PUPPET. Fr., *Poupée;* Ger., *Docke;* Ital., *Toppo;* Span., *Soporte de mandril.*

The upright support of a mandrel in a lathe is termed the puppet or poppet. See Hand-Tools. Machine Tools.

PYROMETER. Fr., *Pyromètre;* Ger., *Pyrometer;* Ital., *Pirometro;* Span., *Pirómetro.*

A pyrometer is any instrument used for measuring degrees of heat above those indicated by the mercurial thermometer, and constructed usually on the principle of registering or measuring, by means of multiplying levers and a scale, the change in length of some expansible substance, as a metallic rod, when exposed to the heat, to be measured.

QUARRYING. Fr., *Exploitation des carrières, Détacher le roc, les pierres;* Ger., *Gestein abtreiben;* Ital., *Cavare;* Span., *Canteria.*

An excavation made for the purpose of obtaining stone is called a quarry. When the object sought is a metal or coal, the excavation is called a mine. A quarry is usually worked open to surface, and is never carried to a great depth; a mine, on the contrary, is rarely worked to surface, and the depth to which it is sunk is in all cases considerable. Quarrying differs little from mining in principle beyond what follows, through the latter being essentially an underground operation.

Quarries are of two kinds, determined by the use to which the excavated material is to be applied; and the mode of carrying out the work of excavation differs in detail in each of these kinds. When the stone is required for building purposes, it is requisite to extract it in that form from which the designs of the builder can be most readily obtained, and at the same time to avoid waste by breaking the stone in an undesirable manner. This necessitates a certain mode of operating, and some care and skill in conducting the operations. But when the shape and size of the pieces of stone extracted are immaterial, as, for instance, in the cases of chalk for lime, stone for road construction and maintenance, or in cuttings through rock for a line of railway. The expeditious removal of the stone is the main object to be kept in view.

In quarrying for any of the above purposes, as, indeed, in all operations, a great object is to produce the greatest results with the available means. And to effect this object, it is necessary to study closely the formation of the rocks in which the excavation is to be made, so as to be able to take advantage of the natural divisions, and by that means to greatly lessen the labour of the quarryman. It must be borne in mind that all rocks belong to one or other of two great classes, namely, the stratified and the unstratified. The former are sedimentary rocks, occurring in parallel beds or strata, and include a large class of most valuable building materials, such as the magnesian lime, sand, and free stone, millstone grit, Yorkshire landings, and other well-known stone. Unstratified or igneous rocks, which include greenstone or whinstone, granite, and porphyry, have no distinct bedding, that is, they do not lie in separate layers. Roofing slate is a stratified rock, but it splits into thinner laminæ in the direction of its cleavage than in that of its bedding, the former being often at right angles to the latter. Some igneous rocks, as granite, have also a natural cleavage, though not stratified. Advantage must be taken of all these peculiarities in order to carry out quarrying operations in an efficient and economical manner.

When the excavation is in stratified rock and the stone is required for building purposes, hand labour is generally preferred to blasting, especially when large blocks for columns, obelisks, tombstones, and similar objects are required. Such blocks are obtained from the more valuable parts of sandstone deposits, technically known as liver-rock; these are the thicker and more consolidated strata. Pieces of limited thickness, as flagstones, are obtained from the thinner beds termed bed-rocks. In quarrying by these means from stratified rocks, a sufficient surface of the rock is first laid bare parallel to the bed of deposit. This portion has then to be disconnected from the general mass by cutting through the stratum or layer, so that it may be removed by sliding upon its bed. To effect the operation, the quarryman, having previously marked out on the exposed surface the size and shape of the stone required, makes a number of small holes with a pick along the line drawn. The distance of these holes apart will depend upon the facility with which the rock can be cleaved. Wrought-iron steel-tipped wedges are then inserted in the holes and struck in succession with heavy hammers until the openings made by them extend from one to the other and also down through the stratum. The block is then free to slide upon its bed, and is removed from its original position by means of iron bars and levers. When the stratum is too thick to be divided in this way, and the stone is of a nature to yield readily to the cutting tool, which is usually a pointed hammer called a pick-hammer, the holes above referred to are sunk deeper, in the form of the letter V, and the wedges inserted in the bottom. Another mode, when the rocks are easily cleaved, is to insert another row of wedges parallel to the natural cleavage. By striking these simultaneously with the others a block is procured of less thickness than the stratum.

When the blocks have been removed from their natural position, they have still to be quarried into shape according to the purpose for which each piece is best suited. Thus, in a building-stone quarry, after the stones of unusual size and quality have been selected for the purposes mentioned above, the larger pieces are roughly formed into ashlar, window-sills, lintels, rybats, corners, steps, and the like, by means of picks, hammers of various kinds, and wedges. The small irregular-shaped pieces are called rubble, and are used for the commonest kind of building. Slates are split up into the requisite thickness by means of a broad chisel and mallet.

The methods we have described apply chiefly to quarries opened for the sole purpose of procuring building stone. But it behoves the engineer who has to execute an excavation in stratified rocks to

consider whether the material removed may not be advantageously employed in the construction of his works, and if such be the case, whether he may not profitably adopt these methods in preference to others which, though more expeditious, spoil a large proportion of the stone.

When the rock is unstratified, or when the stratum is too thick to be disrupted by the wedge without great labour, recourse is had to the action of explosive agents. The explosives most frequently used for this purpose are gun-cotton, dynamite, and gunpowder. Dynamite is now often employed, and always with considerable success. The dangerous character of gun-cotton has hitherto prevented its adoption for ordinary operations, while the comparatively safe character and convenient form of gunpowder have commended it to the confidence of workmen, and hence, for quarrying operations, this explosive is generally employed. We shall therefore, in treating of blasting for stone, consider these operations as carried out by the aid of gunpowder alone.

The system of blasting employed in quarrying is that known as the small-shot system, which consists in boring holes from 1 to 3 in. diameter in the rock to be disrupted to receive the charge. The position of these holes is a matter of the highest importance, from the point of view of producing the greatest effects with the available means, and to determine them properly requires a complete knowledge of the nature of the forces developed by an explosive agent. This knowledge is rarely possessed by quarrymen. Indeed, such is the ignorance of this subject displayed by quarrymen generally, that when the proportioning and placing the charges are left to their judgment, a large expenditure of labour and material will produce very inadequate results. In all cases it is far more economical to entrust these duties to one who thoroughly understands the subject. The following principles should govern all operations of this nature;—

The explosion of gunpowder, by the expansion of the gases suddenly evolved, develops an enormous force, and this force, due to the pressure of a fluid, is exerted equally in all directions. Consequently, the surrounding mass subjected to this force will yield, if it yield at all, in its weakest part, that is, in the part which offers least resistance. The line along which the mass yields, or line of rupture, is called the line of least resistance, and is the distance traversed by the gases before reaching the surface. When the surrounding mass is uniformly resisting, the line of least resistance will be a straight line, and will be the shortest distance from the centre of the charge to the surface. Such, however, is rarely the case, and the line of rupture will therefore in most instances be an irregular line, and often much longer than that from the centre direct to the surface. Hence in all blasting operations there will be two things to determine, the line of least resistance and the quantity of powder requisite to overcome the resistance along that line. For it is obvious that all excess of powder is waste; and, moreover, as the force developed by this excess must be expended upon something, it will probably be employed in doing mischief by shattering stones which it would be desirable to preserve whole. Charges of powder of uniform strength produce effects varying with their weight, that is, a double charge will move a double mass. And as homogeneous masses vary as the cube of any similar line within them, the general rule is established that charges of powder to produce similar results are to each other as the cubes of the lines of least resistance. Hence when the charge requisite to produce a given effect in a particular substance has been determined by experiment, that necessary to produce a like effect in a given mass of the same substance may be readily determined. As the substances to be acted upon are various and differ in tenacity in different localities, and as, moreover, the quality of powder varies greatly, it will be necessary, in undertaking quarrying operations, to make experiments in order to determine the constant which should be employed in calculating the charges of powder. In practice, the line of least resistance is taken as the shortest distance from the centre of the charge to the surface of the rock, unless the existence of natural divisions shows it to lie in some other direction; and, generally, the charge requisite to overcome the resistance will vary from $\frac{1}{15}$ to $\frac{1}{35}$ of the cube of the line, the latter being taken in feet and the former in pounds. Thus, suppose the material to be blasted is chalk and the line of least resistance 4 ft. The cube of 4 is 64, and taking the proportion for chalk as $\frac{1}{30}$, we have $\frac{64}{30} = 2\frac{2}{15}$ lbs. as the charge necessary to produce disruption.

In commencing quarrying operations, the first thing is to find an exposed surface behind which the charge may be placed so as to force it outwards. A vertical surface presents fewer difficulties than any other, both because the resistance in such a case is usually less, and because the proper placing of the charge may be more readily effected. When the blasting is in stratified rock, the position of the charge will frequently be determined by the natural divisions and fissures; for if these are not duly taken into consideration, the quarryman will have the mortification of finding, after his shot has been fired, that the elastic gases have found an easier vent through one of these flaws, and that consequently no useful effect has been produced. The line of least resistance, in this case, will generally be perpendicular to the beds of the strata, so that the hole for the charge may be driven parallel to the strata and in such a position as not to touch the planes which separate them. This hole should never be driven in the direction of the line of least resistance, and when practicable should be at right angles to it.

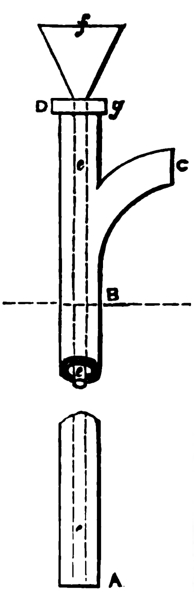
The instruments employed in boring the holes for the shot are iron rods having a wedge-shaped piece of steel welded to their lower ends and brought to an edge so as to cut into the rock. These are worked either by striking them on the head with a hammer, or by jumping them up and down and allowing them to penetrate by their own weight. When used in the former manner they are called borers or drills; in the latter case they are termed jumpers. Recently power jumpers worked by compressed air, and drills actuated in the same manner, have been very successfully employed. Holes may be made by these instruments in almost any direction; but when hand labour only is available, the vertical can be most advantageously worked.

The speed with which holes may be sunk varies of course with the hardness of the rock and the diameter of the hole. At Holyhead the average work done by three men in hard quartz rock with 1½-in. drills was 14 in. an hour; one man holding the drill, and two striking. In granite of good quality, it has been ascertained by experience that three men are able to sink with a 3-in.

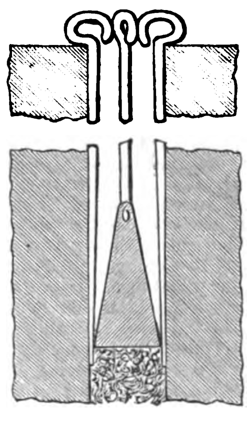
jumper 4 ft. in a day; with a 2½-in. jumper, 5 ft.; with a 2¼-in., 6 ft.; with a 2-in., 8 ft.; and with a 1¾-in., 12 ft. A strong man with a 1-in. jumper will bore 8 ft. in a day. The weight of the hammers used with drills is a matter deserving attention; for if too heavy they fatigue the men, iand consequently fewer blows are given and the effect produced lessened; while, on the other hand, f too light, the strength of the workman is not fully employed. The usual weight is from 5 o 7 lbs.

As the labour of boring a shot-hole in a given kind of rock is dependent on the diameter, it is obviously desirable to make the hole as small as possible, due regard being had to the size of the charge; for it must be borne in mind in determining the diameter of the boring that the charge should not occupy a great length in it. Various expedients have been resorted to for the purpose of enlarging the hole at the bottom so as to form a chamber for the powder. If this could be easily effected, such a mode of placing the charge would be highly advantageous, as a very small bore-hole would be sufficient, and the difficulties of tamping much lessened. One of these expedients is to place a small charge at the bottom of the bore and to fire it after being properly tamped. The charge being insufficient to cause fracture, the parts in immediate contact with it are compressed and crushed to dust, and the cavity is thereby enlarged. The proper charge may then be inserted in the chamber thus formed by boring through the tamping. Another method, applicable chiefly to calcareous rock, has been tried with satisfactory results at Marseilles. When the bore-hole has been sunk to the required depth, a copper pipe, Fig. 6425, of a diameter to fit the bore loosely, is introduced, the end A reaching to the bottom of the hole, which is closed up tight at B with clay so that no air may escape. The pipe is provided with a bent neck C. A small leaden pipe about ½ in. in diameter, with a funnel *f* at the top, is introduced into the copper pipe at D and passed down to within about an inch of the bottom. The annular space between the leaden and copper pipes at *g* is filled with a packing of hemp. Dilute nitric acid is then poured through the funnel and leaden pipe. The acid dissolves the calcareous rock at the bottom, causing an effervescence, and a substance containing the dissolved lime is forced out of the orifice C. This process is continued until from the quantity of acid consumed it is judged that the chamber is sufficiently enlarged. Other acids, such as muriatic or sulphuric, will produce the same effects, but the result of the chemical solution will of course depend upon the nature of the stone.

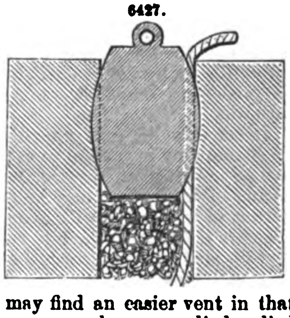
6425.



6426.



6427.



After the shot-hole has been bored, it is cleaned out and dried with a wisp of hay, and the powder poured down; or, when the hole is not vertical, pushed in with a wooden rammer. The quantity of powder should always be determined by weight. One pound, when loosely poured out, will occupy about 30 cub. in., and 1 cub. ft. weighs 57 lbs. A hole 1 in. in diameter will therefore contain ·414 oz. for every inch of depth. Hence to find the weight of powder to an inch of depth in any given hole, we have only to multiply ·414 oz. by the square of the diameter of the hole in inches, and we are enabled to determine either the length of hole for a given charge, or the charge in a given space. It is important to use strong powder in blasting operations, because, as a smaller quantity will be sufficient, it will occupy less space, and thereby save labour in boring.

When the line of least resistance has been decided upon, care must be taken that it remains the line of least resistance; for if the space in the bore-hole is not properly filled, the elastic gases may find an easier vent in that direction than in any other. The materials employed to fill this space are, when so applied, called tamping, and they consist of the chips and dust of the quarry, sand, well-dried clay, or broken brick or stones. Various opinions are held concerning the relative value of these materials as tamping. Sand offers very great resistance from the friction of the particles amongst themselves and against the sides of the bore-hole; it may be easily applied by pouring it in, and is always readily obtainable. Clay, if thoroughly baked, offers a somewhat greater resistance than sand, and, where readily procurable, may be advantageously employed. Broken stone is much inferior to either of these substances in resisting power. The favour in which it is held by quarrymen, and the frequent use they make of it as tamping, must be attributed to the fact of its being always ready to hand, rather than to any excellent results obtained from its use.

To lessen the danger of the tamping being blown out, plugs or cones of metal of different shapes are sometimes inserted in the hole. The best forms of plug are shown in Figs. 6426, 6427; Fig. 6426 is a metal cone wedged in on the tamping with arrows, and Fig. 6427 is a barrel-shaped plug. These mechanical contrivances are employed only in particular circumstances, such as blasting in a shaft; but their efficacy may well be doubted.

In determining the most economic method of obtaining a given quantity of stone from a quarry of any particular description of rock, it is necessary to ascertain, first, the speed with which the bore-holes may be sunk; second, the effects of certain agents, such as small charges or acids, in enlarging the chamber at the bottom; third, the constant from which the charge is to be calculated; and, fourth, the height of face that can be obtained in the quarry. The latter is a very important question economically, for it is obvious, since the charge is placed behind the face, that the higher that face is, the larger will be the mass of rock dislodged. When the face is low, the charge has the same mass to act upon as when the face is high; but in the latter case, a much larger mass is dislodged by its own weight. After these data have been determined, the size of the block required must be considered, and a large charge, or a succession of small charges, applied accordingly. In some quarries large charges are always preferred on account of the less frequent necessity of clearing the quarry of the workmen. To fire the charge a Bickford's fuze is generally employed; this fuze is inexpensive, very certain in its effects, not easily injured by tamping, and is unaffected by damp.

In excavating rock for a railway cutting, a gullet or small cutting is first carried throughout the work, and it is of the highest importance that this gullet should be carried down to the full depth of the cutting. The gullet is then widened by blasting down the faces. The economy of these operations depends in a very high degree upon the skill with which the charges are applied. There is a case on record in which a railway cutting through hard rock was carried down by blasting to a depth of 2 or 3 ft. less than was required of the contractor. To remove these 2 or 3 ft. by hand labour, cost about a guinea a cubic yard, whereas the rest of the cutting averaged only 3*s.* 6*d.* Had the gullet been taken out to the required depth in the first instance, and the charges placed lower, the same quantity of powder would have been sufficient to complete the work.

In quarrying, as in mining, much of the cost is incurred for the removal of water from the workings. A set of pumps and a steam-engine, or a water-wheel where water-power is available, are indispensable for every quarry of any extent. The clearing away of sand, gravel, and other loose débris from the upper bed of the rock also entails considerable expense. This débris, which geologists call drift, and quarrymen tirring, often becomes suddenly very deep, especially when the beds dip at a high angle, and it constitutes an obstacle by which many quarries of stratified rock are soon arrested.

See BORING AND BLASTING. TUNNELLING.

RACK. FR., *Crémaillère;* GER., *Zahustange;* ITAL., *Dentiera;* SPAN., *Cremallera.*

A rack is a straight bar with teeth on its edge arranged so as to gear with those of a wheel or pinion which is to drive or follow it. See MECHANICAL MOVEMENTS.

RAIL. FR., *Rail;* GER., *Schiene;* ITAL., *Rotaia;* SPAN., *Barra-carril.*

See MATERIALS OF CONSTRUCTION, *Strength of.* PERMANENT WAY. RAILWAY ENGINEERING.

RAILWAY ENGINEERING. FR., *Construction des chemins de fer;* GER., *Eisen-bahn Bauten;* ITAL., *Costruzione delle strade ferrate;* SPAN., *Direccion facultativa de ferro-carriles.*

The subject of railway engineering includes all the duties which devolve upon an engineer in the laying out and constructing a line of railway, from the preliminary surveys and levels necessary to the selection of the most eligible route, to the final laying of the permanent way. Some of the more important works of construction inseparable from a line of locomotive traffic, are described under their respective heads, as well as many minor details also connected with the present subject. In England and in Continental countries, certain formalities in relation to the Legislature and the preliminary surveys, must be complied with, previous to obtaining permission from the Government to construct the proposed railway. This is known in England as Parliamentary work, and is nothing more than the observation of certain regulations with regard to the preliminary surveys, laid down by the Government. In every instance it is indispensable to conduct these surveys, and therefore we shall describe the best method of carrying them out in a general point of view, leaving the legal part of the subject out of consideration. All information on this point, so far as Great Britain is concerned, can be obtained from the Standing Orders of the Lords and Commons.

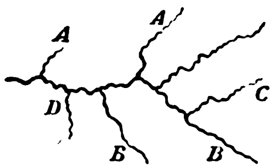
Preliminary Survey or Reconnaissance.—The first step necessary towards the construction of any description of route of communication between two places, whether railway, road, or canal, consists in a preliminary survey or reconnaissance, to use an expressive term frequently employed by military engineers. This reconnaissance requires that the proposed route be either ridden or walked over, and a careful examination made of the principal physical contours and natural features of the district. The amount of care demanded and the difficulties attending the operation will altogether depend upon the character of the country and the condition of civilization to which it has attained. The absence of any map, no matter how incomplete and erroneous it might be, is a serious inconvenience. Engineers who have made only preliminary Parliamentary surveys at home, with the Ordnance maps in their hands, know little of the trouble, delay, and disadvantages attending the absence of all such guides. In the former case they have the bearings marked down for them with all the accuracy requisite for their purpose, in the latter they must obtain them by observations along the journey. It is for this reason that the spirit-levels used by engineers in England are rarely or ever provided with compasses, as the existence of excellent maps renders them unnecessary, whereas they are always attached to the instruments intended for foreign service, when it may be necessary to determine one's whereabouts at any moment.

The immediate object of the preliminary survey is to select one or more trial lines, from which the final route may be ultimately determined. When there are no maps, or when those which can be procured are not sufficiently in detail, points to the right and left of the imaginary line of road must be ascertained by bearings and connected by triangulation with the theodolite. The details may be filled in with the plane table and compass, so as to afford an accurate survey of the portion of the country, more or less wide, through some part of which the proposed route must pass. Many engineers prefer the prismatic compass or the box sextant for filling in details. Sometimes a separate survey must be made of each trial line by a traverse, and villages and other important

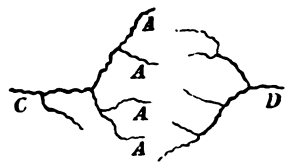
points laid down by taking cross-bearings with the compass. When the several trial lines are all plotted to the same scale, a good map can be prepared from which the exact line of road can be selected. In making a reconnaissance there are several points which, if carefully attended to, will very considerably lessen the labour and time otherwise required. Lines which would run along the immediate bank of a large stream, must of necessity intersect all the tributaries confluent on that bank, thereby demanding a corresponding number of bridges. Those again which are situated along the slopes of hills are more liable, in rainy weather, to suffer from washing away of the earthwork and sliding of the embankments, than others which are placed in valleys or elevated plateaux. When a line of railway crosses the ridges dividing the principal water-courses, the ascents and descents are greater, and the cost of working the finished line will be proportionably increased.

The position of summit levels, important features to be determined in selecting a line of railway, road, or canal, may be ascertained by observing the direction and size of the existing water-courses. The diagram in Fig. 6428 shows that the water falls from C to D, and also transversely from A A A and B B in the direction of D. In Fig. 6429 the ridge is broken along the line A A, from which the water flows in both directions towards C and D. In order to join the points A and D in

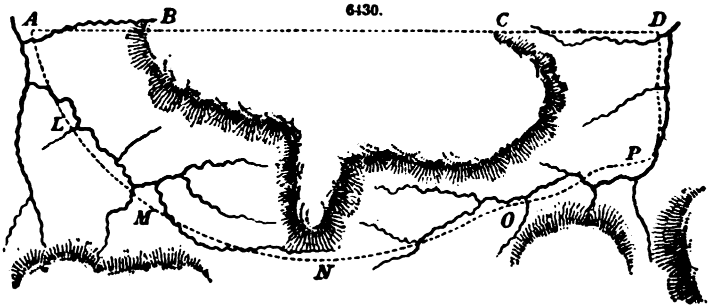
6428.



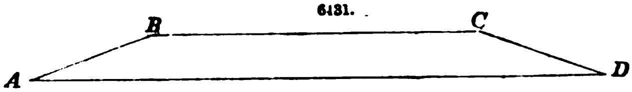
6429.

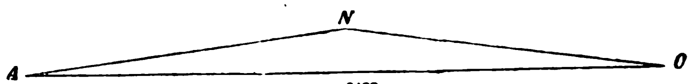


6430.



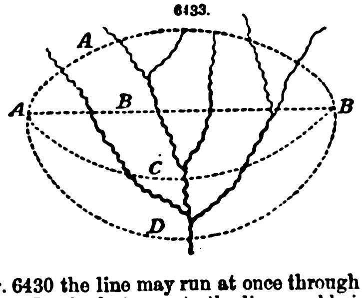
6431.





6432.

6433.



6434.

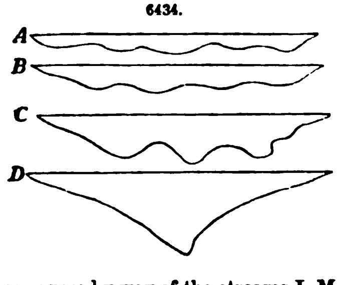
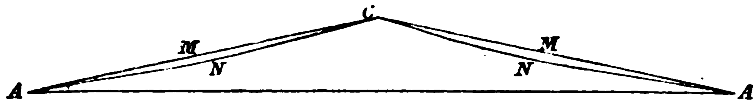


Fig. 6430 the line may run at once through B and C, or it may pass by way of the streams L M and O P. By the latter route the line would rise along the whole distance from A through L and M to the summit at N, and fall from N through O and P to D If the district between B and C consists of an elevated plateau, the longitudinal sections of the two lines will be represented in Figs. 6431, 6432, by A B C D and A N D. If the line passes from A to B in Fig. 6433 by the several routes A, B, C, D, the corresponding sections will be as shown in Fig. 6434. The conclusion to be drawn from these diagrams is that the difference of elevation to be overcome will be a minimum when the line crosses at the head of the streams.

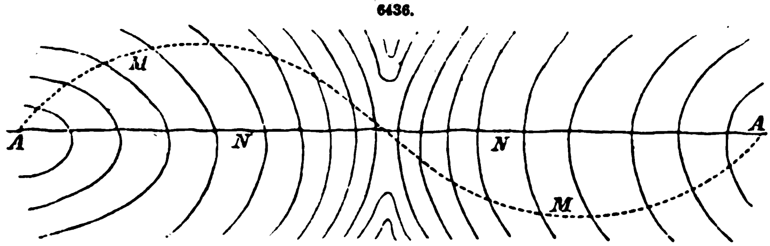
Trial Lines by Compass.—When the line of railway has been approximately found by the recon-

naissance, a trial line may be run by compass through those parts of the district which present the most favourable features. It may be roughly staked out, and the leading topographical details right and left of it sketched in. If the trial line should follow the bed of a stream, it will have a contour A M C, as shown in Fig. 6435. The lowest line of the valley, although moderately inclined at first, rises more and more rapidly in the direction of the source of the stream as represented by the closer approach of the contour lines on the plan in Fig. 6436. If it be required that the line should rise uniformly from A to the summit level, the horizontal distances between the contour lines must be all equal throughout the whole ascent. This equality may be ensured by causing the line to cut the contours at right angles during the first part of the ascent, and obliquely as the summit level is approached. By these means the contour lines become nearer to one another, and we obtain the section A M M A on the plan in Fig. 6436. The contour line is level. The line cutting the contour line at right angles is the steepest line the ground allows of, and the inclination can be varied at pleasure between those limits. A very good idea of the result, so far as the section is concerned, of cutting the contour lines in different distances is shown in Figs. 6437, 6438. If the points A and B be connected upon the plan in Fig. 6437 by the straight line A B, we obtain the section

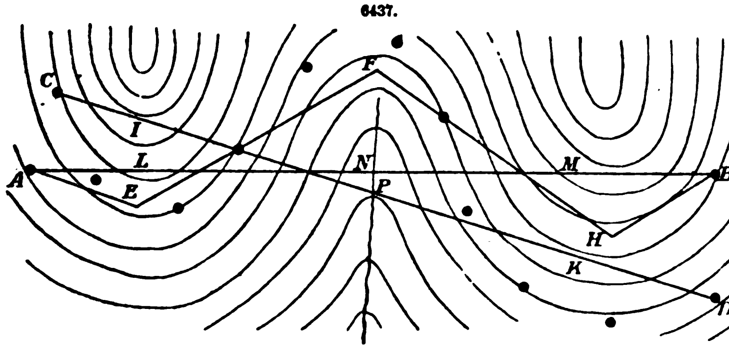
6435.



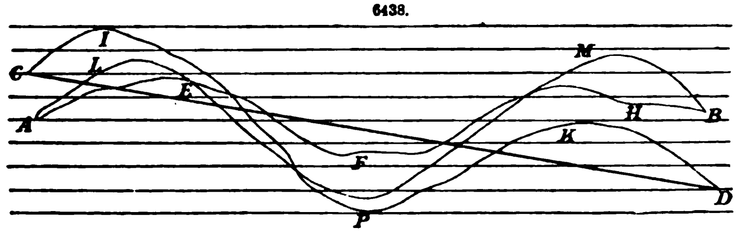
6436.



6437.



6438.



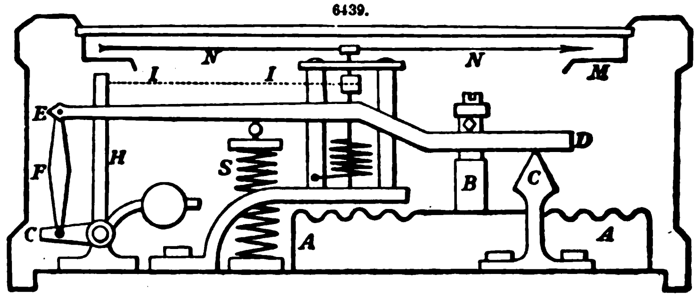
shown by A L N M B in Fig. 6438. If the route follow exactly the direction of the contour line from A to B, all the points are on the same level; and the section will be represented by the horizontal line A B in Fig. 6438. If the route run midway between the straight line A B and the contour line A E F H B, the corresponding section will be given in Fig. 6438 by A E F H B. If the points C and D, which are at different elevations, be connected by the straight line C D in Fig. 6437, the section will be represented by C I P K D in Fig. 6138. To descend at a uniform rate of inclination from C to D, the rate must be known, and the vertical distance between the contour lines. The corresponding horizontal distances between the contour lines are then known, which, applied as by the dots in Fig. 6436, give the required descent. The corresponding section is shown in Fig. 6438 by the straight line C D. The line A E F H B on the plan is longer than the

straight line A B, and the contour line is longer still. This increased length is not represented in the section in Fig. 6438, as the object is merely to show the general relation between the plan and section, and the use of correctly-drawn contour lines in adjusting any route to the ground.

Trial Lines by the Aid of a Map.—When the map of a district is procurable, the task of laying down one or two trial lines from which to select the final route, becomes more or less difficult in proportion to the scale of detail to which the map is drawn. Supposing that a really good map is obtainable, something approaching English Ordnance maps, the operation is as follows;—Map in hand, the engineer walks over the ground, marking on the plan certain points through which the trial lines are to pass. The points are connected together by straight lines and curves of given radii, and the line or lines are then ready to be levelled over, in order to ascertain which of them presents the best section or profile, as it is sometimes called. In instances in which the proposed route will probably run for a portion of its length along one or other of the banks of a stream, trial lines must be made on both banks, not only in order to determine the best longitudinal section, but also to discover the number of tributaries or feeders which belong to each side, since every one of these necessitates a bridge, or at least a diversion of the stream.

Trial or Flying Levels.—When once the trial lines have been marked on the map, the levelling is done by an ordinary instrument in the same manner as for the final route, which will be described in its proper place. But in countries of which there is no map, and in which the natural features are extremely rugged, the levels along a proposed route cannot be taken by the spirit-level. A less precise, but more portable, and more easily manipulated instrument must be employed. It must be borne in mind that in new countries in which there are no buildings, no private demesnes, and no vested interests to interfere with, the selection of a line of railway depends altogether upon the longitudinal section. For this reason the exact route is of little consequence, and the preliminary survey is limited, in the first case, to determining the relative altitudes of certain points through which, or in the vicinity of which, the line must pass. If we suppose for a moment that the altitudes of ten obligatory points have been ascertained, it is a simple question of winding the line between them, or, in other words, lengthening it until the maximum gradient which can be worked, is obtained. Flying levels are taken with great convenience and sufficient accuracy for the purpose by means of an excellent little instrument called the aneroid barometer. This instrument consists of a flat cylindrical metallic box, exhausted of air, the top of which is made very thin, and corrugated in concentric circles, in order to render it more elastic. When the atmospheric pressure increases, this corrugated top is forced inwards or downwards. When, on the other hand, the atmospheric pressure decreases, the elasticity of the metal, aided by a spring or a counterweight, tends to move it in the opposite direction. This movement of the top of the box is conveyed by a series of multiplying levers to an index moving over a circular scale, graduated to correspond with the structural barometer. The several parts of this instrument are shown in Fig. 6439. A A is the metallic box, with corrugated top, exhausted of air, and fixed to the bottom

6439.



of a brass case enclosing the mechanism of the whole instrument. B is a small column connecting the top of the box with the principal lever E D, the latter moving upon the fulcrum C. The movement of the small end of the lever is carried by the rod F to the short end of the bent lever G H, to the upper end of which is attached the watch-chain I I. This chain passes round a small drum upon the arbor carrying the needle N N at its upper end.

A small hair-spring upon the arbor regulates the motion of the needle. S is a spiral spring, which, by its tension, raises the principal lever E D, when the pressure on the top of the box is in any way lessened. The circular scale, seen in section at M, is graduated by comparing its indications under different pressures with those of a standard mercurial barometer.

With a good aneroid a difference of 10 ft. in elevation may be detected. The mercurial column in the cistern barometer falls, in round numbers, 1 in. for each 1000 ft. of ascent. The amount of motion of the aneroid needle corresponding to 1 in. of the mercurial column depends upon the size and proportions of the instrument. With the outer case 5 in. in diameter, the needle is 3 in. long, and the diameter of the graduated circle the same. 1 in. on the mercurial column is represented upon such a circle by an inch and a half. This inch and a half is called an inch, and is divided into ten parts; and each of these again is subdivided into five parts; and as these smaller divisions are easily halved by the eye, the $\frac{1}{100}$ of an inch, which corresponds to a difference in elevation of only 10 ft., is readily determined.

To use the aneroid, the following rule has been prepared;—As the sum of the readings at the different stations is to their difference, so is 55,000 to the elevation required. Thus, if the reading at the foot of a hill is 30·05, and at the top 29·44, the sum is 59·49, and the difference 0·61; whence the proportion 59·49 to 0·61, as 55,000 to 564 ft. At the back of the aneroid is placed a

small screw, by means of which the needle may be set in either direction, so as to correspond with a standard barometer. In measuring an elevation, or in running lines of levels, the aneroid should be compared with a standard barometer or with another aneroid at the commencement and at the termination of the work, and at frequent intervals between, in order to detect any irregularity in the instrument. The aneroid is chiefly useful in working from one known elevation to another, to determine the approximate heights of intermediate points. For long-continued observations, unchecked, or for long profiles, the barometer is of little or no use.

The instrument should be carefully handled, and when used held in a horizontal position, in order that the counterweight may act properly. For nice work, an allowance should be made for variations in the temperature, both of the air and of the instrument.

This has not been commonly done in using the aneroid, though the results would certainly be more reliable if this point was regarded.

Flying levels may be taken by the plane-table by adjusting it carefully to the horizontal position, measuring the tangent of the angle of altitude or depression and multiplying it by the distance.

When the barometer is employed for taking preliminary or flying levels, the following formulæ may be used for calculating the difference of level at the different points where the observations are made. Let H and H_1 represent the height of the mercurial column in the barometer at the lower and higher stations respectively. Put T and T_1 for the corresponding temperatures at the two stations of the mercury in degrees of Fahrenheit, as shown by the attached thermometer, and T_2 and T_3 for the temperatures of the air in degrees of Fahrenheit, as shown by the same thermometer. Then, putting H_2 for the height of the higher station above the lower, we have

$$H_2 = 60360 \{ \log. H - \log. H_1 - 0{\cdot}000044 (T - T_1) \} \left(1 + \frac{T_2 + T_3 - 64}{986}\right).$$

When rapidity of calculation is more desirable than great accuracy, the value of H_2 sufficiently exact for all practical purposes is given by the equation

$$H_2 = 56300 (\log. H - \log. H_1) \left(1 + \frac{T_2 + T_3}{900}\right).$$

If tables of logarithms are not at hand, and when the height does not exceed 3000 ft. the barometric reading at the higher station may be corrected by making $B = H_1 \left(1 + \frac{T - T_1}{10000}\right)$, from which $H_2 = 52428 \frac{H - B}{H + B} \left(1 + \frac{T_2 + T_3 - 64}{986}\right)$.

These formulæ are applicable also to the aneroid barometer, with the exception of the correction depending on the temperature by the attached thermometer. The aneroid barometer may be constructed in such a manner as will enable all corrections for the effect of its own temperature on its indications to be dispensed with. If it be required to correct the difference of level for variations in the force of gravity, the value already found for H_2 must be multiplied by

$$1 + 0{\cdot}00284 \cos. 2\lambda + \frac{H_3}{104 \cdot 50000}.$$

In the equation λ is the mean altitude of the two stations or points of observation, and H_3 the mean of their heights in feet above the level of the sea.

Flying or preliminary levels may be also taken by determining the boiling point of pure water by a sensitive thermometer. The boiling point falls very nearly at the rate of one degree of Fahrenheit, for every 543 ft. of ascent. The exact rate may be thus determined; Let F = height in feet, then $F = 517\ (212° - T) + (212° - T)^2$, in which T is the boiling point in Fahrenheit's scale and F the height of the station where the experiment is made, above a station where the boiling point is 212°. To compare the levels of two stations the boiling point of pure water is to be observed at each, and the quantity F calculated by the formulæ for each of the boiling points. The approximate difference in level will be the difference of the values of F corrected for the temperature of the air.

The use of flying levels, besides affording general information with regard to the proposed route, is to determine the elevation of detached points of great importance respecting the cost and feasibility of the line. It is frequently at these spots where constructive works of great magnitude are required, and unless a tolerably approximate idea of their relative level can be previously ascertained, it is impossible to make an estimate of the expense of the whole undertaking. In an old country the levels are frequently made subservient to the plan, that is, that there are so many objects to be avoided in order to prevent incurring heavy compensation and other serious expenses, that the direction of the line is often of more importance than the levels and gradients. The reverse is the case in new countries and colonies. The direction of the line, so far as the land is concerned, is of no consequence. It is the question of the levels which virtually decides whether the line is actually practicable, and determines the route which it must follow.

Selection of Route.—In deciding on a project for a railway, the engineer will have to form an opinion as to whether the expenditure will be repaid, and to select the route which secures the greatest traffic, and at the same time involves the least expenditure. He has to decide whether the amount of traffic to be expected will warrant the construction of a first-class railway, or whether a railway of a lighter description will suffice, cheaper to construct, but of correspondingly less carrying power. Such problems involve statistical, political, and commercial considerations, as well as engineering ones.

There are certain items in the construction and maintenance of railways which are independent

of the route selected, but there are others which, on the contrary, are altogether dependent upon it. The various items which regulate the rate at which goods can be conveyed upon railways are as follows;—

1st. The interest on the capital expended during the construction of the line. As this charge, for a given line, is a fixed sum, its influence on the cost of transport will be in the inverse ratio of the quantity of traffic.

2nd. Of the cost of repair and maintenance of the railway, including the earthworks, the permanent way, the buildings, the rolling stock, and the apparatus employed in working.

3rd. Of the cost of police.

4th. Of the cost of traction, which is proportional to the traffic.

5th. Of the expenses of management and working, proportional in part to the traffic, and partly independent of the quantity of traffic.

On English railways only about 50 per cent. of the capital expended before the opening of the railway has been spent on the actual works of construction. Of the remainder about 20 per cent. on the average has been laid out in the purchase of land, about 10 per cent. in the purchase of carrying stock, and the remainder in law expenses, discounts, and other preliminary charges.

Of the gross receipts, taking one year as a sample, 7 per cent. was absorbed in maintenance of permanent way, 18 per cent. in locomotive and wagon expenses, 12 per cent. in traffic charges, and 10 per cent. in police rates and other expenses, amounting to 47 per cent. altogether, and leaving 53 per cent. for payment of dividends.

It is important to notice the relative proportions of these items, because they indicate the order of precedence of the questions to be considered in the selection of a line of railway. It is easy to show from these figures that the augmentation of the traffic holds the first rank amongst the considerations determining the choice of route, and that economy of construction takes precedence of questions depending on the expenditure of locomotive power.

For a colonial line the cost of construction bears of course a larger proportion to the gross preliminary expenditure; the cost of land may be reduced, and other preliminary items, unavoidable in an old country, vanish. In the construction of the Mauritius Railway the land cost 17 per cent. of the preliminary expenditure, and nearly the whole of the remainder was due to cost of construction and rolling stock. Obviously, in such a case, economy of construction is relatively of greater importance.

If all the traffic is between two terminal points, then the best direction for the road is the straight line joining them, because, other things being equal, the straight road being the shortest will be the cheapest to work, and the least expensive to construct. For through traffic the only reason for departing from the straight direction is the necessity of avoiding heavy works of construction; and the question whether a straight line involving difficult works, or a more circuitous but easier route is to be preferred, resolves itself into the question whether the annual saving of cost of carriage and maintenance, due to the less length of the more direct route, is greater or less than the interest of the excess of outlay due to its adoption. And since the annual saving of transport on the shorter distance will be proportional to the quantity of traffic, it is obvious that the greater the amount of the traffic, the more the outlay which may be incurred to secure the shortest road.

In the earlier railways in England, constructed at a time when the power of the locomotive was very limited, all other considerations were sacrificed with a view to the attainment of the most direct and most perfect line. Indeed, directness was held only second to the necessity of easy gradients. No expense in heavy works of construction was spared, either in shortening the line or reducing its gradients. Locke was the first to break through this rule, and his system, known at the time as the undulating system, was to follow as far as possible the undulations of the ground, and to diminish to the utmost the cost of construction, by avoiding heavy works. To that end he not only permitted his lines to deviate from the direct route, but he introduced gradients of 1 in 70 to 1 in 80, or five times as steep as the ruling gradient on the London and Birmingham, twelve times as steep as the ruling gradient of the Liverpool and Manchester, and nearly twenty times as steep as that of the Great Western.

All the tendency of railway engineering since Locke's time has been to follow the direction indicated by him; instead of ranking flatness of gradient first, directness second, and economy of construction third, in considering the route to be adopted, that order might almost be said to be inverted in all but exceptional instances of large and assured traffic.

Independently of quantity of traffic as affecting the outlay on a railway, the necessity of economy of construction becomes of paramount importance in new countries. In America it is often necessary to push forward a railway into new districts long before the traffic has assumed defined directions, or its future amount can be estimated with any certainty, and when capital for construction of an expensive line cannot be found. In such cases the railway has to be constructed as cheaply as possible, almost without regard to the effect of the sacrifices to secure that end on the ultimate cost of transport. The establishment of such a line is, in America, immediately followed by the settlement of population in the adjacent country, the introduction of industry, and the development of natural resources; and by the time the cheap structure is worn out the profits have usually been sufficient to replace it by a more durable and perfect one. Such a course, however, is not to be justified in a country where the population is tolerably fixed and the traffic can be estimated with some degree of certainty. In that case, the question between the cheaper and the more expensive route is, simply, in what way will the total cost of transport, inclusive of interest charged on outlay, be made a minimum?

When it becomes a question how far the railway shall deviate from the straight line, not only to reduce the cost of works of construction, but to secure increased traffic, the question is a still more complex one. If a railroad is very short, the larger proportion of its traffic is through traffic;

but the longer it is, the larger the proportion which the local bears to the through traffic. The majority of passengers do not travel more than 25 miles, and the same rule holds with freight. A straight and direct line serves best the through traffic between the terminal points, but it serves very badly the intermediate district. In England, in France, in America, and in India, the importance of the local traffic has proved much greater than was at first expected, and is now so much more generally recognized than it used to be, that it is impolitic and prejudicial to sacrifice the intermediate districts to the terminal ones. In India the local traffic pays much more than the through traffic, and it has in some instances been found worth while to make a considerable detour in order to pick it up, instead of leaving it to find its way to the main line, or attempting to serve it by branches. The real question in such a case is, how far will the reduction of the cost of carriage, due to the augmentation in quantity of the traffic, compensate for the increased expenditure in traction and maintenance of the longer line?

Gauge.—The gauge of a line depends upon several conditions, such as the gauge of lines already existing, which must be placed in communication with the proposed railway, the amount of traffic likely to be developed, the pecuniary condition of the country, and the local features of the route. The gauges at present of lines worked by locomotives vary from 1 ft. 11½ in. to 7 ft. ¾ in., the former being that of the Festiniog Railway, and the latter that of the Great Western. The latter may, however, be regarded as exceptional and obsolete, as it is rapidly giving place to the standard gauge of 4 ft. 8½ in. In the article Permanent Way, some particulars are given of the various gauges adopted in English colonies and elsewhere. A break of gauge, or the construction of some lines in the same country of a different gauge to others, is very undesirable, although this has taken place in India. The means by which to guard against this error, is not to construct the first lines in the country of a gauge in excess of the requirements of the traffic. It is easy in countries in which the land is not of any great value to lay down an additional line of rails, which will enable more trains to be run, when necessary, without necessitating an increase in the size of the locomotives and rolling stock generally. A broad gauge means a corresponding increase in the size of all the standing works of the line, and consequently an increased expenditure in their construction. Instead of adhering to any particular standard, the gauge of a line in a new country should be selected, as that which will be sufficient for the demands likely to be made upon it for many years by the traffic of passengers and goods. In Japan, for instance, a gauge of 3 ft. 6 in. has been adopted. The manner in which the gauge affects the standing works of the line, and the transverse area, will be apparent from an inspection of Fig. 6440 and Table I., in which all dimensions are in feet and inches.

6440.

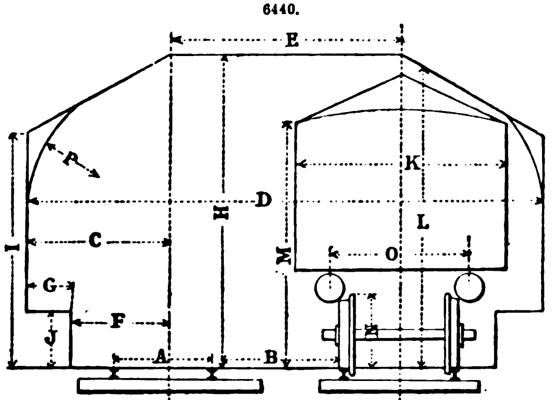


Table I.

Gauge.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.	P.
Broad ..	7·0¾	6·0	7·0	27·5	13·5	5·7¼	1·4¾	16·0	14·0	2·9	9·6	14·3	11·7	3·1	5·10	6·0
Standard	4·8½	6·0	6·7	24·3¾	11·1¼	4·7	2·0	14·6	11·0	2·0	8·4	13·6	11·7	3·4	5·8	2·0
Irish ..	5·3	6·0	8·2	28·0	11·8	4·9	1·7½	14·6	10·6	2·9	10·0	13·3	11·6	3·5	6·2	8·0
Indian ..	5·6	6·0	6·11½	24·10	11·11	5·2½	1·9	14·6	11·6	3·0	10·6	13·6	11·6	3·6	6·5	3·0
Prussian	4·8½	6·2¼	6·7	24·6	11·4	5·5	1·2	15·9	15·9	2·6	8·7	13·6	12·0	3·5	5·9	6·7

Although the wider the gauge, the wider the rolling stock, as a rule, yet the breadth of the carriages does not depend altogether upon that of the gauge, because the overhang, or the projection of the sides over the metals, may be varied to a certain extent, according to the opinion of the engineer. It is evident that with a gauge of very limited dimensions, if the overhang is considerably out of proportion, the carriages will rock very much, and dangerously so at high speeds. As the gauge diminishes, and the overhang increases, the whole system becomes approximated to a single rail with the rolling stock balanced upon it. The rocking or lurching of carriages becomes sometimes very serious, especially when the six-foot or ordinary distance between any pair of rails is reduced, as occurs at stations and at those spots at which junctions and sidings take place. Accidents have happened at these points by reason of the sides of the carriages coming in contact. In all cases the gauge is measured from the inside of the head of the rails. Wheels which are designed for one particular gauge will run over others in which the difference does not amount to more than an inch one way or the other.

Gradients and Curves.—The considerations which governed the adoption of gradients on ordinary roads were for a long time supposed to apply to the locomotive, and to fix the proper ruling gradient on railways at about 1 in 250. There has been much discussion as to the gradients which a locomotive was capable of ascending, and as to whether the power expended on the ascending gradients

was or was not recuperated on the descending ones. It was at no very distant period predicted by a leading engineer that the working expenses of gradients of 1 in 40 would amount to such a sum as to more than swallow up any possible receipts. And on the earlier lines, in several instances, where steep gradients could not be avoided, stationary engines were erected to draw up the trains by rope traction. Now the case of the locomotive is in many respects very different from that of a horse on a metalled road. The tractive power of the engine for a given effective steam-pressure is constant, and nearly independent of the velocity, and the adhesion is constant. Hence a reserve of tractive force for surmounting difficult parts of the line can only be obtained by working the engine over the other parts of the line at less than the full power of which it is capable, and therefore uneconomically.

But, on the other hand, the resistance on railways is not, like the resistance on roads, independent of the velocity. Hence an engine will take up a gradient, at a slow speed, the load which it is capable of drawing at a much higher speed on the level; and since, generally, some variation of speed may be permitted without objection, a compensation is thus afforded to the otherwise prejudicial influence of the gradient. Again, if the gradient is only a short one, then the locomotive may, so to speak, take the gradient at a run, and, by gradually expending in the ascent, part of the work accumulated in approaching it, may also take up a heavier load than would otherwise be possible. Both these considerations help to explain why the influence of gradients on the cost of traction on railways has been much less than the earlier engineers supposed would be the case. The most important consideration, however, is that the locomotive expenses form only about one-third of the whole expenditure on transport; and since the power expended on the gradient affects only this item of the expenditure of working the line, it may easily be seen that there may in other ways be compensation to such an extent as to quite hide the influence of the gradients. The Lancashire and Yorkshire is a line with very heavy gradients and with very heavy traffic; but neither the expenditure on maintenance of way, nor the expenses of traction a train mile, nor the proportion of the expenditure to receipts, differ much from that on other lines on which the gradients are much more favourable.

But when the inclines are long and the traffic heavy there is no doubt that steep inclines have a very great influence on that part of the total cost of transport comprehended under the head of locomotive expenses; and if a judgment is to be formed as to the desirability or not of permitting a heavy gradient, it must be by comparing the excess of cost of working due to the gradient with the saving in cost of construction, or in other ways which its adoption permits. Desgranges has shown, in the Bulletin of the French Society of Civil Engineers, how great is the influence of the Soemmering incline on the cost of working the railway on which it occurs; and similar results have been published in regard to the Giovi and Poretta inclines.

Let us suppose an engine of the maximum ordinary weight, say 48 tons. If all the wheels were coupled, and the coefficient of adhesion were taken at $\frac{1}{9}$, the adhesion would be in round numbers 1200 lbs. That the tractive force might be equivalent to this adhesion, supposing the cylinders 18 in. diameter, 24-in. stroke, and the driving wheels 4 ft. diameter, the mean effective steam-pressure would require to be 50 lbs. on the square inch.

Taking the resistance of a train at 10 miles an hour at 7 lbs. a ton, that of the engine at 13·5 lbs., with 1 lb. extra for friction, this engine would draw on the level a train load of 1600 tons. On an incline of 1 in 100 the train load would have to be reduced to 375 tons; on an incline of 1 in 40 it would have to be reduced to 187 tons, and on an incline of 1 in 27 it would only take up a load of 81 tons. Lastly, on an incline of 1 in 10 nearly, the engine would only be able to take up its own weight.

Now, practically speaking, the cost of the engine power would be the same to the mile whether the engine were dragging behind 1600 tons on the level, or only taking its own weight up in 1 in 10. It is obvious, therefore, that on railways the ruling gradient has a great influence on the locomotive expenses.

In the above instances the work of the engine was limited simply by the adhesion. Let us suppose, next, that in place of carrying a maximum load the engine is required to work at a maximum speed. In this case the work of the engine will be chiefly limited by the evaporative power of the boiler, but the gradients will have an equally striking influence. Suppose the same engine modified so as to have a single pair of driving wheels, the weight on which is 15 tons and the adhesion 3750 lbs., and let the engine be capable of developing 400 horse-power and work at a minimum speed on the gradients of 40 miles an hour. The tractive force of the engine will be $\frac{400 \times 33000 \times 60}{5280 \times 40} = 3750$ lbs. If the resistance of the train be taken at 20 lbs. and that of the engine at 20 lbs. also, then on the level $(48 \times 20) + (P \times 20) =$ or < 3750, $\therefore P =$ or < 140 tons. On an incline of 1 in 100 $(48 \times 20) + (P \times 20) + (P + 48)\frac{2240}{100} =$ or < 3750, $\therefore P = 40$ tons; and on inclines greater than 1 in 37 the engine would be unable to maintain the speed with no train at all.

At the present moment the problem with engineers is not so much how to construct lines with easy gradients as how locomotives can be constructed to work gradients of maximum steepness. The Accrington incline of 1 in 37, the Oldham incline of 1 in 27, the Soemmering incline of 1 in 40, the Indian Ghât incline of 1 in 37, the Giovi incline of 1 in 36 and 1 in 27, have now been worked for years with ordinary locomotives. The navigation incline of the Taff Vale Railway, originally constructed for rope traction, is now worked by locomotives, the maximum gradient being 1 in 17·8, and the average 1 in 20 for half a mile. The engines which work this incline weigh, in working order, 36 tons, and they have six coupled 4-ft. wheels, 16-in. cylinders, 24-in. stroke, and work with a boiler pressure of 130 lbs. The maximum load they will take up the incline is 45 tons, and the regulation load 25 tons. The Mauritius Railway has gradients varying from 1 in 60 to 1

in 27, there being $2\frac{1}{4}$ miles altogether of the latter gradient, and 6163 ft. in a continuous length. The railway rises in all 1817 ft. in 16 miles, and descends an equal distance in 19 miles on the other side of the ridge. This railway is worked by tank engines weighing 48 tons with eight coupled wheels 4 ft. in diameter, the cylinders being 18 in. diameter, 24-in. stroke, and the steam-pressure 120 lbs. These engines take ordinarily five passenger carriages and a brake van, weighing altogether 42 tons, and on some occasions have taken 56 tons. The running speed of the passenger trains is 16 miles an hour, or, including stoppages, 12 miles; the ordinary load of goods trains in descending is 100 tons, though 120 tons have been taken. The ordinary running speed for goods trains is 12 miles, or, including stoppages, 9 miles an hour.

On the Soemmering incline of 1 in 40, engines of the same dimensions take up passenger trains weighing 130 tons, and goods trains of 175 to 200 tons. Engines of 43 tons weight take trains of 190 tons up the Glyn Neath incline of 1 in 47 for 5 miles; at 7 or 8 miles an hour a 56-ton engine has taken 300 tons at $6\frac{1}{2}$ miles up the same incline. On the Copiapo Railway in Chili, which has been worked by locomotive power for six years, there are inclines of as much as 1 in 20, and in the direction of the heaviest traffic of as much as 1 in 23. This railway rises 2276 ft. in $14\frac{1}{2}$ miles and then descends 1990 ft. in $9\frac{1}{2}$ miles. The engines are outside cylinder engines with six coupled 4-ft. wheels and a 4-wheeled bogie in front. The weight of the engine in working order is 32 tons, and the adhesion weight 24 tons; the ordinary load is 50 tons, exclusive of the engine and tender, and a load of 77 tons was on one occasion taken over the inclines of 1 in 23. It appears that in Chili an adhesion of one quarter the weight on the driving wheels has been attained, and that one-fifth is utilized with the ordinary load. But the climate of Chili is peculiarly favourable, there being little rain.

During the construction of the Baltimore and Ohio Railway temporary lines with maximum gradients of 1 in 10 were constructed over the tunnel ridges for the conveyance of materials. Engines weighing 27 tons took one car weighing 14 tons over these inclines. And over a similar temporary line with gradients of 1 in 16 and 1 in 20, the same engine took regularly, for six months, three cars, weighing 15 tons each.

In the face of these facts the opinion of engineers has undergone a complete revolution on the question of steep gradients, and perhaps the tendency at the present moment is to adopt gradients even steeper than is desirable. As the power of the locomotive has increased, the possibility of surmounting steep gradients has increased in the same ratio, and the question of ruling gradient is much less exclusively dependent on the available power, and much more dependent on the natural configuration of the country.

No one would adopt steep gradients from choice. Still, cases will arise where a certain liberty of choice of gradient is afforded, and this may arise in two ways. The engineer may have choice between a longer line with a flatter gradient, and a shorter with a steep gradient; or he may have choice between lines nearly equal in length, one of which is a surface line with heavy gradients, the other a line in which ease of gradient is secured by tunnelling or heavy works of construction. In either of these cases the primary question is, to decide which alternative renders the sum of the expenses of traction and interest on outlay a ton of load carried, a minimum, and in ascertaining that the cost to the train mile may be assumed as approximately constant.

The following approximate formula will be found convenient for estimating the train load which a given engine will carry, supposing all the wheels coupled. $P^1 = P^2$, then

$$P = \left(\frac{f}{\cdot 0000026\, V^2 + i + \cdot 0036} - 1\right) P^1.$$

For large and heavy traffic at high speeds it is worth while to incur almost any expenditure to obtain the best gradient possible. If the traffic is lighter, or chiefly passenger traffic, but the speed still required to be great, a somewhat steeper gradient may be adopted, say 1 in 100 to 1 in 150. If the traffic can be worked at slow speeds the gradient may be greater still; 1 in 40 is the limit prescribed in the economical railway system in Norway. If the climate is such that a large coefficient of adhesion can be depended on, then the experience in Chili shows that inclines of 1 in 20 to 1 in 25 may be worked by ordinary locomotives. Finally, if we change the structure of the locomotive, as Fell has done, we may surmount gradients of 1 in 12. The less the individual weight of trains to be transported the steeper the gradient which may be permitted.

There is, however, one aspect of steep gradients which requires notice, and that is, the increased danger attending the working. A train, the resistance of which is 7 lbs. a ton, will descend an incline of 1 in 320 by its own weight, and on greater inclines its motion will be accelerated. The same happens to ordinary goods engines with coupled wheels on inclines of 1 in 100, and to passenger engines on inclines of 1 in 150 to 1 in 200. If the incline is a long one the acceleration in descending, due to gravity, may become dangerous, and the train may require to be controlled by the brakes, which involves a waste of power in friction and increased destruction of the permanent way. Now it appears that in fine, dry weather the retarding power of brakes is from 400 to 470 lbs. a ton of the weight on the wheels to which the brakes are applied; but that in misty weather the average retarding force is only 120 lbs. a ton, or $\frac{1}{18}$ of the weight. Hence, in misty weather, on inclines of more than 1 in 18 a carriage would descend by gravity alone even though its wheels were skidded, and in dry weather the same would happen on inclines of more than 1 in 5.

The distance in which a train could be stopped by the brakes in descending an incline of 1 in $1 \div i$, supposing them to be applied when the train is travelling at a velocity of V miles an hour, would be in feet $V^2 \div 30\,(f^1 - i)$, where f^1 is the proportion of the resistance caused by the brakes to the weight of the train. In wet weather, on inclines like those on the Mauritius Railway of 1 in 27, supposing the velocity attained before the application of the brakes to be 20 miles an hour, and with the brakes applied to all the wheels of engine and train, the distance required to bring the train to rest would be $20^2 \div 30\left(\frac{1}{18} - \frac{1}{27}\right) = 720$ ft.

It is not, however, usual to brake the engine wheels except in emergencies, because the action of the brakes has been found to heat and loosen the wheel tires. Now, for goods trains with a 48-ton engine and 80 tons train, the coefficient of resistance would be reduced to $\frac{1}{18} \times \frac{80}{128} = \frac{1}{25}$. In that case, with all the train wheels braked, the distance required to arrest the train on an incline of 1 in 27 would be increased to $20^2 + 30\left(\frac{1}{25} - \frac{1}{27}\right) = 4500$ ft. During less than two years' working, trains have got beyond control on the Mauritius Railway five times, attaining once an average speed over four miles of 45 miles an hour, but in other instances terrible accidents have occurred from this cause.

Resistance of Curves.—Curves increase the resistance also in a degree not very well known. Rankine found the additional resistance due to curves, for light passenger-carriages, with truly cylindrical wheels to be in lbs. a ton, 1·4 ÷ radius of curve in miles. But he points out that if the wheels are not truly cylindrical, but somewhat coned, as is more common, the resistance on the level line will be increased, and that on the curves diminished, so that the difference between the resistance on the level and on curves will be less felt.

Experiments in America by Latrobe give for the resistance on curves in lbs. a ton, 0·578 ÷ radius in miles.

MM. Vuillemin, Guebhard, and Dieudonné found no sensible increase of resistance with passenger trains at low speeds on curves of more than 75 chains radius. At 35 miles on a curve of 75 chains the resistance of a passenger train was increased by 5 per cent., or the resistance due to the curve was 0·8 ÷ radius in miles. For goods trains, the additional resistance at 16 miles on curves of 50 and 40 chains was about 1·5 ÷ radius in miles. The passenger trains consisted of twelve carriages, and the goods trains of forty wagons. The increase of length of train appears to increase the frictional resistance on curves by rendering the line of traction oblique.

Assuming, as sufficiently accurate for the purpose, that the resistance from curvature is inversely as the radius, it follows that there is the same resistance experienced in running 1 mile of a curve of 2 degrees as in running 2 miles of a curve of 1 degree. In both cases the number of degrees of deflection is the same. The total resistance is proportional to the whole number of degrees traversed, and is independent of the radius or length of the curve theoretically considered.

The average of numerous experiments would seem to show that the resistance upon a 10-degree curve, or a curve of 574 ft. radius, at a speed of 20 miles an hour, is double that upon a straight line.

In traversing therefore a 10-degree curve, a mile long, we should consume an amount of power sufficient to haul a train 2 miles upon a straight line. The length of a 10-degree curve is, however, only 574 × 2 × 3·1416, or 3606 ft.; and this, being a whole circle, contains 360°. The proportionate number of degrees in a mile, or 5280 ft., is 527; which is thus the number of degrees, whatever the radius, consuming an amount of power which would haul a train 1 mile on a straight and level road at 20 miles an hour; and this is therefore the equating number for comparing the curvature upon different lines, just as 24 ft. was the equating number for the comparison of gradients at the same speed. But, as in the case of grades, a double expenditure of power does not involve a double cost. We, however, increase the cost of operation more in doubling the resistance by curvature than we do in doubling it by gradients, since the effect of curvature upon the wear and tear of the engines, cars, and track, is greater than that of gradients. Taking the operation of the 1500 miles of railway in Massachusetts as a basis, and adding, for a double expenditure of power, demanded by curves, 25 per cent. to the cost of repairs of the roadway, engines, and cars, and 100 per cent. to the cost of fuel, we shall increase the whole expense of operating and maintaining the road by about 25 per cent. If therefore a mile of road containing 527 degrees of curvature demands the exertion of double the power required upon an equal length of straight line, and if the exertion of a double power involves 25 per cent. more expense, the number of degrees consuming an amount of money sufficient to operate and maintain 1 mile of road will be $\frac{100}{25}$ of 527, or 2108 degrees; which is thus the equating number for curvature at a speed of 20 miles an hour. This number, however, being based upon a double resistance, will vary according to the actual resistance upon a straight line, and thus according to the speed, as shown in the following Table, where column 3 gives the radius of the curve upon which the resistance is double that upon a straight line, these radii being made inversely to the resistances in column 2. The number of degrees of deflection in column 4 is found by the proportion, rad. (col. 3) × 3·1416 × 2 to 5280 as 360° to No. in col. 4; and the numbers in column 5 are $\frac{100}{25}$ of those in column 4, and may be used as the equating numbers for curvature.

TABLE II.

Speed in miles an hour.	Resistance in lbs. a ton.	Radius of Curve of Double Resistance.	Corresponding No. of Degrees in a Mile.	Equating No. in Degrees.
15	9·3	636	476	1904
20	10·3	574	527	2108
25	11·7	506	598	2392
30	13·3	444	682	2728
40	17·4	340	890	3560
50	22·6	261	1159	4636

Inasmuch as the expense of operation is more increased by sharp than by easy curvature, just as it is more increased by steep than by light gradients, we should vary the equating number, in any comparison of surveyed lines, as we varied the equating number for gradients in the example upon a preceding page. It is, however, impossible to say, with any exactness, what this variation should be, since we have no means of knowing what effect the sharpening of the curvature has upon the working expenses. The general effect is, of course, to make the equating number smaller for sharp curves, and larger for curves of large radius. Suppose we have surveyed two lines, the first being 100 miles long, and having 4216 degrees of curvature, and the second being 98 miles long, and having 8432 degrees of curvature. At a speed of 20 miles an hour, the equating number is 2108 degrees, and the equating distances $100 + \frac{4216}{2108}$, or 102 miles; and $98 + \frac{8432}{2108}$, or 102 miles. If we assume the cost of operation to be as the equated length, we may compare any number of routes, by adding in each case the cost of construction to the operating expense of the equated length, capitalized. From what has been said, it may be seen how important it is to guard against the introduction of gradients and curves without carefully considering their cost. We have regarded gradients and curves only as demanding a greater locomotive power, and as causing an increased wear and tear of track and machinery.

When, however, a road is liable to be worked up to its full capacity by gradients or curves it becomes a much more serious matter. The capacity of a road being limited by the number and weight of trains that can be run over it, if by increasing the resistance by gradients or curves, the trains are reduced in weight one-half, the capacity of the road is reduced by the same amount, and the cost of transportation is doubled.

In estimating the amount to be spent in reducing gradients or curves, we are of course to regard the effect of these elements upon the cost of operation in the same manner as above stated in the case of simple distance; but the interest upon the cost of construction which applies to distance, does not apply to gradients or curves. Thus, while a certain number of feet of ascent, or of degrees of curvature, may be regarded as equivalent to a mile of distance, in the matter of operation, they are less objectionable by the amount of interest upon the cost of building a mile of road.

Cost of Transport over any given Line.—Having decided upon the line of railway to be adopted, it will be useful to make a tolerably accurate estimate of the cost of the carriage over it, after having ascertained the necessary data. The cost will be nearly constant to the train mile, and its amount a ton of paying load will depend, first, on the gross load which the engine will draw, and, secondly, on the ratio between the paying and the non-paying load. Put W for the gross weight of the train in tons, exclusive of engine and tender, which the engine will draw. Let R = the resistance of the train in lbs. a ton, W_1 = the weight in tons of the engine and tender, R_1 = the resistance of the engine and tender as vehicles in lbs. a ton, V = the velocity of the train in miles an hour, N = the number of effective horse-power which the engine can develop exclusive of the friction of the machinery, W_2 = the adhesion weight of the engine in tons, and F = the coefficient of adhesion. The effort in running will be $W \times R + W_1 \times R_1$ in lbs. The work a second expended by the engine is $1{\cdot}47\,(W R + W_1 R_1)\,V$ in *foot lbs.* In order that the engine may move the train, the power must not be less than the latter quantity, and the adhesion not less than the former, so that to fulfil these conditions we have $1{\cdot}47\,(W R + W_1 R_1)\,V =$ or $< N \times 550$, and also $W R + W_1 R_1 =$ or $< 2240 \times F \times W_2$. If the line, instead of being level has a ruling gradient equal to G, then the above equations become $1{\cdot}47\,\{W R + W_1 R_1 \pm 2240\,(W + W_1)\,G\} =$ or $< 550\,N$ and $(W R + W_1 R_1) \pm 2240\,(W + W_1)\,G =$ or $< 2240\,F\,W_2$. In finding the value of R an approximate value for the gross weight of the train must be assumed, the weight of the train must then be calculated, and if the latter result does not agree with the former, the new weight must be used in finding R, and a second approximation obtained.

Experiments have proved that for very low speeds the resistance of a train of carriages or wagons is simply proportional to its weight under given conditions, but that at higher speeds it increases rapidly. For slow speeds the value of R is about 7 lbs. a ton. Making W as before the gross weight of the train in tons, R the resistance in pounds a ton, and V the velocity in miles an hour, we have the following values for R according to the conditions of each particular case.

1st. For goods trains at 8 to 20 miles an hour,

$$R = 3{\cdot}64 + {\cdot}177\,V \text{ (for axles lubricated with oil)},$$
$$R = 5{\cdot}08 + {\cdot}177\,V \text{ (for axles greased)}.$$

2nd. For passenger and mixed trains, at speeds of 20 to 30 miles an hour,

$$R = 4 + {\cdot}283\,V + \frac{{\cdot}283\,V^2}{W}.$$

3rd. For passenger trains at 30 to 40 miles an hour,

$$R = 4 + {\cdot}283\,V + \frac{{\cdot}187\,V^2}{W}.$$

4th. For express trains at 40 to 50 miles an hour,

$$R = 4 + {\cdot}495\,V + \frac{{\cdot}126\,V^2}{W}.$$

The resistance of the engines and their tenders, considered as vehicles, is greater than that of the train. The experiments on the friction of engines when drawn along the line by another engine, are less complete than those on the friction of carriages and wagons, but it appears that the resistance of goods engines and tenders is about $2\frac{1}{2}$ times as much a ton as that of the train; and

the resistance of engines with one pair of driving wheels is about $1\frac{1}{4}$ times that of the train, a speeds not exceeding 30 miles an hour.

Within this limit the following formulæ give the resistance of engines, considered as carriages, that is, independently of the friction of the working parts when under steam.

$$\begin{aligned} &\text{Goods engine} \quad R_1 = 9\cdot 1 + \cdot 442\,V, \\ &\text{Mixed engine} \quad R_1 = 5\cdot 5 + \cdot 265\,V, \\ &\text{Express engine}\ R_1 = 4\cdot 55 + \cdot 221\,V. \end{aligned}$$

At higher speeds the resistance of the engines, considered as vehicles, probably becomes sensibly equal to that of the train. If, instead of being drawn by another engine, as a vehicle, the engine has itself to draw the train, then the friction of its working parts increases, and a further addition is made to the resistance. Vuillemin, Guebhard, and Dieudonné have found, by calculating the actual engine power in one instance, that about 15 per cent. of the whole power of the engine was expended in the transport and friction of the engine itself, so that the tractive force on the draw-bar was 0·85 only of that calculated from the steam pressure. A common allowance for the extra friction of the working parts of the engine, when running with the load on, is 1 lb. a ton of the engine weight.

Thus far the resistance on the level has been considered; if, instead of being level, the line has a gradient, then the action of gravity increases the resistance, if the train is ascending, and diminishes it if descending. If the gradient is 1 in $\frac{1}{\theta}$ so that θ is the sine of the angle of inclination, and R is the resistance on the level, then the resistance to ascending the gradient is in lbs. a ton $R + 2240\,\theta$, and in descending $R - 2240\,\theta$.

An approximate formula by Clarke for train resistances is convenient for calculation. If R_1 = the resistance of engine, tender, and train in lbs. a ton of gross weight, then

$$R_1 = \frac{V^2 + 1368}{171} = 8 + \frac{V^2}{171}.$$

Similarly, if R_2 = the resistance of the train alone in lbs. a ton,

$$R_2 = \frac{V^2 + 1440}{240} = \frac{V^2}{240} + 6.$$

These formulæ do not take into account the friction of the machinery. The resistance due to the friction of the working parts of the engine with the load, together with that of the engine and tender considered as vehicles, is given by Clarke as in lbs. a ton weight of engine and tender. Calling this resistance R_3, we have the equation

$$R_3 = \left(\frac{V^2}{240} + 6\right) + \left(\frac{V^2}{600} + 2\right)\frac{W + W_1}{W}.$$

In this equation the first quantity $\left(\frac{V^2}{240} + 6\right)$ is the resistance of the engine and tender as vehicles, while the second quantity $\left(\frac{V^2}{600} + 2\right)\frac{W + W_1}{W}$ represents the resistance due to the friction of the machinery.

Estimate.—As the object is to reduce the cost of the line to a minimum, the gradients should be laid out so as to balance the respective quantities in the cuttings and embankments. Moreover, in laying down the gradients, attention must be paid to all details which may affect the cost of the work, such as the heights of floods, and the sections of the roads which have to be crossed either by an under or over bridge. At points where it is proposed to place stations, the gradients for a length of 7 or 800 ft. must be flat, if it is not possible to introduce a horizontal piece of that length. In determining when tunnels are to be made, regard must be had to the means of running out the material supposing an open cutting were to be substituted. The simplest case is that in which a tunnel is made instead of a cutting which would be run to spoil, and the height at which it becomes cheaper to substitute the tunnel may be thus found.

Let H = the height in feet, B the base of the cutting, R the ratio of the slopes, P the price of the cutting a cube yard, and P^1 the price of the tunnel a yard run. The price of the cutting a yard run will be given by the equation $P\,(B\,H + R\,H^2)$, which by the question must be equal to P^1, so we have $H\,(B + R\,H) = \frac{9 \times P^1}{P}$. Solving the quadratic we finally obtain $H = \sqrt{\frac{9 \times P^1}{P \times R} + \frac{B^2}{4\,R^2}} - \frac{B}{2\,R}$. Instead of the cutting being run to spoil, if it should be wanted to make up an embankment, the cost of the side cutting thus required must be charged against the tunnel in the estimate of its cost. The principal items in the estimate of a line of railway, not including the locomotives and rolling stock, are as follows;—Excavation, soiling and sowing slopes, fencing, road metalling and pitching, ballast, boxing, public and farm road level crossings, bridges, tunnels, diversion of streams and roads, culverts and drainage, laying the permanent way, maintenance of way. It will generally be found cheaper to divert roads and streams instead of building bridges either under or over them. In the latter case the interests of mill-owners and riparian manufacturers must be taken into consideration.

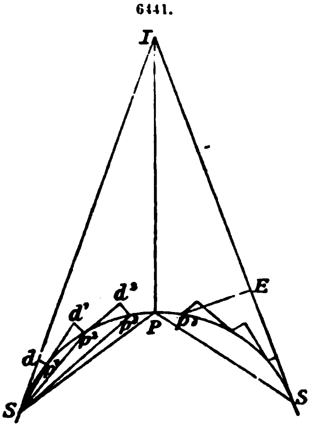
Staking and Setting Out the Line and Works.—The chain used is generally either the 66-ft. or 100-ft. chain. The latter possesses many advantages over the former, especially in the convenience

it affords in calculations of estimates and gradients. The only disadvantage the 100-ft. chain labours under is, that it lacks whatever convenience is supposed to appertain to the fact of 10 square statute chains being equal to an acre; but in reality this is of no account. The first thing to be done in the field is, to mark out the centre line of railway, putting in a stake at every distance of 100 ft., or whatever may be the length of the chain used. The centre line of railway, no matter how curved, may be considered as a series of intersecting straight lines joined by curves, and the process of staking is based on this view. For ranging straight lines, or setting out curves, the transit theodolite is the proper instrument to employ. A line is transferred from the map to the ground by putting up five or six poles, or more, according to its length, at well-defined points on it, such as the crossing of a fence at a measured distance from another fence. When these are erected with flags on them, two are selected to represent the line, and the rest taken down.

In placing stakes for any structure, they should be so far outside the work that they will remain undisturbed during future operations. The stakes for excavations for foundations should be placed at the angles, and the working points must be so placed that lines stretched from one to the other will define the permanent superstructure. Two stakes placed at a moderate distance apart upon the land will determine any line on water, and two sets of stakes, upon different lines on land will by their intersection determine any point upon water with all the accuracy necessary for practical purposes. A permanent bench mark or B.M., should be established and accurately checked at the beginning and ending of all cuttings and embankments, and intermediate ones put in at intervals of about 5 or 600 ft. These B.Ms. should also be fixed at a short distance from every bridge, viaduct, or other permanent structure on the line, so that the requisite levels can be given to the workmen with precision and facility. All bench marks should be registered for future reference at any time.

The ranging the straight portions of a line is so simple an affair, that with ordinary care and attention an error is scarcely possible; it is in the curves that errors are liable to be made, which are often not perceived until half the curve is laid out, and even sometimes are only discovered by the curve not coming in at its proper springing point, thus necessitating a repetition of the process of putting in the curve. Of the numerous methods at present known, some have been furnished by scientific persons laying no claims to professional practice, and consequently are of a purely theoretical nature; while others, though practically available, are only calculated to meet the requirements of such very exceptional cases that their utility is exceedingly questionable. Excluding these as for obvious reasons unsuitable to the present subject, the remainder may be classed under two heads;—1st, the methods by offsets which dispense with the use of an angular instrument; and 2nd, the methods which require the use of such instruments, or the methods by angles, as they have been called. In laying out curves by the former methods the necessary instruments are chain, ranging rods, offset-staff, or tape, where the offsets exceed 10 ft. in length. In the latter the offset-staff is replaced by a theodolite, plain or transit; or a portable altitude and azimuth instrument might be used if a theodolite could not be obtained, though the preference should always be given to the theodolite as the proper instrument for laying out curves by the methods of angles. In the following investigation we shall take Rankine's method as the best example of putting in curves by means of angles, partly because this elegant and generally useful method is becoming more and more adopted every day; and partly because the other examples of a similar kind are based upon the assumption that the springings, that is the commencement and termination of the curve, or each springing, and the intersecting point of their tangents, are visible from one another—a condition which rarely occurs in practice. In the diagram, Fig. 6441, let S S_1 be the terminations of two straight portions of a railway which are to be connected by the curve S P S_1; S S_1 will thus be the two springings of the curve, P a point in the middle of the curve, commonly but erroneously called the secant point, and I the intersecting point of the tangents to the curve, or straight portions of the line.

6441.



It may be observed that in all the methods included under the first head, where no angular instrument is employed, the springings cannot be obtained with any great pretensions to accuracy, for they must of necessity be taken from the plan. We shall suppose the staking out of the line to have been proceeded with as far as S, which will be the commencement of the curve or first springing, and that the stakes are driven at regular intervals of 100 ft. apart, both in the straight and curved portions of the line; we shall also assume, for simplicity's sake, the point S to be at one of these stakes, although it is right to mention that when the springings are obtained by the use of a theodolite,—that is, generally, by observing the angle of intersection S I S_1. Fig. 6441, calculating the length of the tangent I S, and chaining to the point S,—the chances are that it will never coincide with one of the 100-ft. stakes; on the contrary, by the methods by offsets where S is assumed, it would be sufficiently accurate in the majority of cases, and far more convenient, to take one of the regular stakes as the springing, and thus save the calculation of an additional offset.

In Fig. 6441 let p_1, p_2, p_3, be points in the curve 100 ft. apart; and let us now examine the manner in which their positions are determined, confining our attention, for the moment, to the left-hand half of the figure, which will serve to demonstrate the principles of Rankine's method and the common method by offsets. In the latter method the measured distances S d, p_1 d_1, p_2 d_2, and in the former S p_1, p_1 p_2, p_2 p_3, are assumed equal to the arcs, S p_1, p_1 p_2, p_2 p_3. This is practically correct within certain well-known limits, and when necessary the error can be reduced, either by

calculation, or by driving the stakes closer to one another, say 50 instead of 100 ft.; this, however, is not required except in very sharp curves. By the method of offsets the point p_1 is obtained by chaining the distance S d = 100 ft., and laying off at right angles the calculated offset $d\ p_1$; similarly the point p_2 is obtained by chaining $p_1\ d_1$, and setting off d_1, p_2, and so on. By the other method, suppose the theodolite planted at S, the angle I S p_1 is laid off = angle for one chain, and the chain stretched from the point S; where it intersects the line of direction given by the instrument will be the required point p_1; the point p_2 is obtained by setting off the angle I S p_2 = twice the former angle, and intersecting the line of direction by the chain, one end being firmly held at the last obtained point p_1; and so on until the nature of the ground renders it necessary to remove the instrument to one of the stakes whose position has been previously determined, when the same process is resumed and continued to the end of the curve.

It is evident that by the former method the position of any point in the curve depends absolutely and entirely on the position of the preceding ones; this, however, is not the case when the theodolite is used; for, take the point p_2 for instance, the line of direction of this point is given by the angle I S p_2 and is totally independent of the position of the point p_1; and it should be observed that the lines of direction are obtained with a precision which the most practised and dexterous manipulation of the chain and offset-staff can never attain.

It is true, notwithstanding this, that any error in the chaining would certainly produce an error in the position of the point p_2; but, in our present comparison, it is equally just to assume the errors incidental to chaining as common to both methods, or, what amounts to the same, to consider the chaining accurately performed. We then have the accuracy of laying off the offsets balanced against the accuracy of the theodolite. The difficulty of performing the former correctly increases with the length of the offsets employed; or supposing the measured distances constant, inversely as the radius; the reverse happens with the theodolite, for, as the angles to be laid off are thus increased, the lines of direction are all the more likely to be accurate. Progressive errors are common to both these methods, but the points P and S_1 act as certain and reliable checks in the latter, respecting both distance and direction; these checks are wanting in the former method, and in fact all that can be done is to lay out the curve as accurately as possible, and take the chance of it coming in at the point S_1, which chance, especially if the curve be a long one, is very small indeed, as may be imagined, when the inventor admits that in many cases "the curve has to be frequently retraced several times before it can be got right."

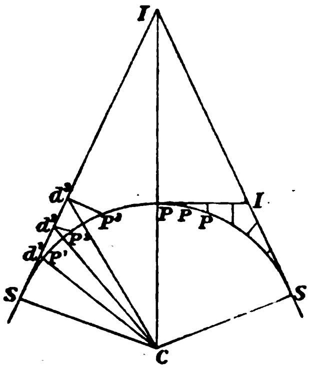
There are certain exceptional cases, however, in which this method, on account of its requiring so few preliminary calculations and lines on the ground, is valuable; as, for instance, where any intermediate stakes in a curve have been lost or destroyed, as frequently occurs during the progress of the works of a line. By simply producing the chords joining any two stakes, and laying off the correct distances and offsets, the missing stakes can be restored with ease and facility; also in road approaches, road diversions, and all similar instances where the curve is short and great accuracy not required, this common method will be found very useful. In order to obviate the progressive errors arising from using such short distances as one chain, greater lengths may be taken and the proper offsets measured from them; but, as the regular stakes would have to be put in afterwards, this modification of the preceding method, besides being liable to the same errors, involves the absolute necessity of putting in the curve twice at least.

The right-hand portion of Fig. 6441 serves to show the demonstration of this; the errors due to progression being reduced by calculating the distance S_1 E, so that the measured offset Ep_3 may serve as a check on the point p_3, one of the regular stakes to be afterwards filled in. It may be urged as an objection to the method by angles, that a great deal of inconvenience and delay is incurred in chaining the tangents I S and I S_1, Fig. 6441, in order to obtain the accurate position of the springings of the curve S and S_1; these points, however, may be accurately found in another manner whenever the middle point P in the curve is previously determined; for let the instrument be set up over P, and the angles I P S and I P S_1 laid off, each being equal to 90° plus half the angle in the whole curve, which give us the lines of direction P S and P S_1, and all that remains is to produce them until they intersect the two straight portions of the line in S and S_1; the nature of the ground will be the best guide respecting which of these means should be employed for the above purpose.

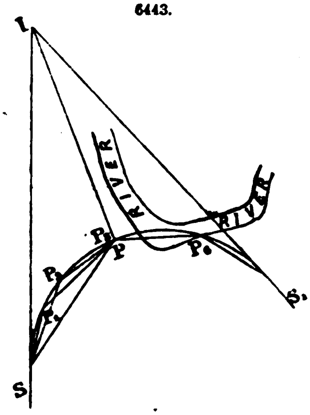
Another example of the methods by offsets is shown in the diagram, Fig. 6442, in which S P S_1 is the curve, and the remainder of the figure is self-explanatory. Taking the left-hand portion of the diagram first, it will be seen that the distances are measured along the tangent line S_1, and the offsets measured perpendicularly, which, it is manifest, in long curves of small radius, would assume such lengthened proportions as to render it impossible to lay them off accurately. As a rule, to ensure the proper degree of accuracy in the points of the curve in the example in Fig. 6442, the length of the curve should not exceed one-fourth of its radius, so that this method becomes inapplicable to curves possessing radii of lengths greater than from one-eighth to one-quarter of a mile, which last is even a very short curve. This example has an advantage over the first described, Fig. 6441, inasmuch as the progressive errors cannot go beyond half the curve, for the offsets for the remaining half are obtained from an independent datum, namely, the other tangent line S_1 I; the liability to error is also further lessened in consequence of the direction of the lines along which the distances are measured remaining constant instead of requiring to be changed for every offset, as in the example given before. This advantage is partially lost in long and sharp curves, when, in order to keep the lengths of the offsets within proper limits, it becomes necessary to run two or more tangent lines as base lines to measure the offsets from, as shown on the right-hand portion of Fig. 6442; in fact, it amounts to this, that in order to reduce the chances of error in one direction we are compelled to incur the chances of making them in another. In the place of measuring the offsets perpendicularly to the tangents, they may be set off in the radial direction whenever the centre of the curve is visible from the necessary portions of its circumference; but this is a case which very rarely occurs in practice. When the curve is short and the radius large, these two methods approximate very closely

to one another, for the difference between the offsets measured perpendicularly and those measured radially to the tangents becomes very small.

6442.



6443.



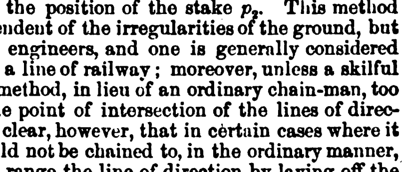
There is another example of laying out curves by the method of angles which is worthy of notice, though, in reality, a modification of the method mentioned above; the same principles and preliminary calculations are available, but the position of the points is determined by the intersection of two lines of direction given by two theodolites working at the same time, the intermediate chaining being dispensed with. The diagram, Fig. 6443, will serve to render this clear. Let S P S_1 be the curve, and we will take a case in which, as often happens, the springings, though not visible to one another, can be seen from P, the middle point of the curve. Suppose it is required to put in the stake p_2; let one theodolite be set up at S, and the other at P; by the former let the angle I S p_2 be laid off, and the line of direction S p_2 obtained. The line P p_2 is similarly obtained by the latter instrument, and the point of their intersection is the position of the stake p_2. This method has the advantage of all others in being perfectly independent of the irregularities of the ground, but is very seldom used as it requires the services of two engineers, and one is generally considered sufficient for the staking out of each allotted portion of a line of railway; moreover, unless a skilful assistant were employed capable of comprehending the method, in lieu of an ordinary chain-man, too much time would be wasted in shifting about, before the point of intersection of the lines of direction of the two instruments could be determined. It is clear, however, that in certain cases where it was required to obtain the position of a stake which could not be chained to, in the ordinary manner, it might be well worth the time of the engineer to first range the line of direction by laying off the proper angle for that stake, and then shift his instrument to some other previously determined point in the curve, and lay off another line of direction, their intersection giving the required point. For instance, let it be necessary to put in the stake p_6 in the right-hand portion of Fig. 6443, which comes on the bank of a river through a part of which the line goes; suppose the instrument set up at P and the line of direction P p_6 ranged, then removed to the point S_1 and $S_1\,p_6$ obtained, and the position of p_6 is determined.

Most of the formulæ and calculations required for the different methods described are to be found in text-books on the subject; but the following general formula for the method of angles will be found useful from its great simplicity and facility of calculation. Let a = any length of arc, r the radius of the curve, and θ the required angle for that length of arc; then $\theta = \dfrac{a \times 28\cdot648}{r}$, θ being the angle between the chord and tangent of the arc, and thus obtained in degrees and decimals. Putting a = 100 ft., we have in round numbers $\theta = \dfrac{2865}{\text{radius of curve}}$. In order to apply this formula to a practical example, the following proof is adduced;—

In Fig. 6444, let the arc A B C be portion of a railway curve which it is required to lay off by Rankine's method; that is, by means of the angle contained between its chord and tangent. Let A I = the tangent we use in this case, and A C = chord of arc; a = length of arc A B C, R = radius of curve, and θ = angle required. We have the following proportion; $\theta° : 45° :: a : \dfrac{\pi R}{2}$, π = ratio of circle to diameter = 3·1416, from which we obtain

$$\theta = \frac{90\,a}{\pi\,R} = \frac{a}{R} \times 28\cdot648.$$

6444.



This equation gives the value of θ in degrees and decimals for any length of arc, thus being of service in the finding of the angle for what is known as the odd distances.

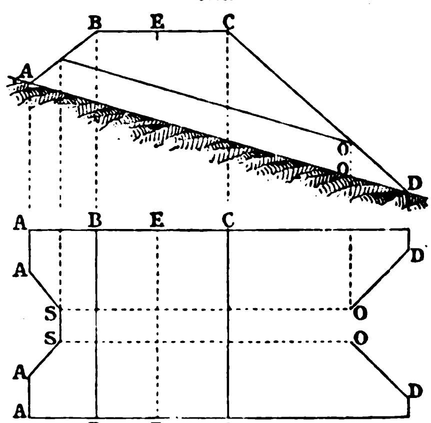
Supposing θ to be known, as it always is for the whole curve, by transposing the equation we find the following value for the length of the arc; $a = \dfrac{\theta \times R}{28\cdot648}$, bearing in mind that in both these

equations a and R must be in the same terms. By means of these two equations we obtain very important data for laying out curves by this method, without requiring the use of tables of logarithms or natural sines, very valuable, but, to say the least, very troublesome aids to calculation in the field. If in the formula we put $a = 1$ chain, and multiply the right-hand side of the equation by 60, we obtain for θ the following value in minutes and decimals; $\theta = \frac{1719}{R}$. This will be found a very convenient and useful formula to use in the field, when text-books and tables of logarithms are not always at hand.

Setting Out the Side Widths.—An ordinary method of setting out the side widths on the ground is by a tentative process of combined levelling and calculation, which is nothing better than a mere rule of thumb. A table should be made out from the cross-sections of the line, which are taken as often as the character of the ground requires, and the distances set out at right angles to the centre lines. When the land is level, the side widths are readily obtained by adding to the height of the cutting or embankment, multiplied by the ratio of the slopes, a constant, which depends on the width of the formation level and the description of fence put up. When the land is sloping transversely to the direction of the line, the side widths must be taken from the cross-sections, and measured horizontally on each side of the centre. The side widths are always laid off at every stake along the line, and where the ground is very rough, at intermediate distances also.

Setting Out Culverts.—The length of a culvert which passes under an embankment is less than the distance between the bottom of the opposite side slopes, and may be thus found. Put L for the length of the culvert in feet, H for its height in feet, H_1 for the height of the embankment, B for the breadth of the embankment at top, and R for the ratio of the slopes; then $L = (B + 2 R H_1) - 2 R H$. When the natural surface of the ground is horizontal, the length of any structure passing under an embankment will lie half on each side of the centre line. When the natural surface is inclined, the ends of the structure will be at different distances from the centre line, according to the slopes of the ground. This is seen in Figs. 6445, 6446, the first of which represents the section, and the second the plan, of an embankment. The lines S S and O O, representing the ends of a culvert passing beneath the embankment, are seen to be at different distances from the centre line. The position of the points S and O may be found by first getting from the tables of side widths the points A and D, and measuring in from these points the distances A S and D O, depending upon the slopes A B and A D. In the case of the upper end, the distance of S S from A will be less than if the natural surface was level; at the lower end, the distance from D to O will be greater. Having found the distances of S S and O O from the centre line, we get the position and length of the wing walls of the culvert by drawing a line from S to any desired angle to intersect the slope A A; and upon the lower side of the embankment we get, in the same manner, the lines O D, O D, the latter being, of course, longer than the wings upon the upper side A S, A S.

6445.



6446.

Setting Out Bridge-work.—In laying out the abutments for bridges, there are numerous cases to be considered; as, whether the bridge is on the square or on the skew, upon a level or a gradient, upon a curve or a straight line, and whether the natural surface is horizontal or inclined. The position and form of abutments and wing walls depend so much upon the various conditions affecting each particular case, that any attempt to lay down general rules for such work would be of little use.

In a curving viaduct consisting of a series of arches which exert a thrust upon the masonry, the piers should be made radial to the centre line of the curve, and the springing lines should be made parallel to the axes of the arches.

Calculation of Acreage.—The acreages to be calculated are always small, seldom exceeding a couple of acres, excepting in the case of considerable demolition of property. It will be found that the calculations can be made in feet as readily as if the divisions on the scale represented links. But should it be preferred to calculate in links, the operation can be effected by having a corresponding scale made to measure with. Thus, if the plan is plotted to a scale of 200 ft. to 1 in., a scale divided with 30·303 divisions to the inch will enable the measurements in links to be taken off. When all the measurements are made in feet, the advantages of the 100-ft. chain are so evident as to completely outweigh any slight convenience which may result from having the plan plotted to links. The acreage is usually taken out in statute measure, and is so marked on the plan and sometimes in plantation measure also.

Setting Out Tunnels.—The maintaining of a correct centre line for a tunnel is a very important operation, and one requiring the greatest care. The fixing of the line at the bottom of shafts demands every precaution, owing to the short distance between the only points that can be transferred from the surface to the bottom. The centre line of the road is first run over the ground to be tunnelled, fixing exactly the position of the shafts. To transfer this line from the surface to the bottom when the shafts are completed, let two posts be sunk into the ground a few feet apart, one being on each side of the centre line, at a short distance from the opening, so as to be undisturbed by the progress of the work. Upon the opposite side of the shaft let two more posts be fixed in the same manner. Place a stout cross-bar in a horizontal position upon each pair of posts, and upon the

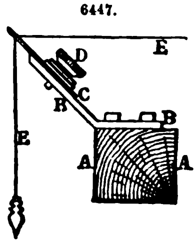
side of each bar fasten a stiff piece of metal, which shall have a V-shaped notch cut in it. The two notches being so adjusted that the bottoms of the V's shall be exactly upon the centre line of the tunnel, pass a steel wire through them, and stretch it tight by weights hung from the ends. Next, suspend within the shaft, as far apart along the line of the road as the opening will allow, two heavy plumbs, carefully turned, and attached to strong wires long enough to reach to the bottom, the upper ends being so arranged that the plumb-lines may be moved into exact contact with the horizontal wire stretched between the notches.

At the bottom of the shaft place two stiff and well-seasoned bars of wood across the tunnel, at a distance apart of 50 or 60 ft., and 3 or 4 ft. above the ground, adjusted at the ends into metal fixtures let into the side walls, so that the bars may be removed and accurately replaced at pleasure.

Let a metal slide with a V-shaped notch be attached to each of the bars, with a clamp for fixing it to the same when in the proper position. Stretch a fine wire across these two lower notches, and move the slides until they come correctly into the direction of the plumb-lines, and fasten them. The two lower notches will then be upon the centre line of the road, which may be produced in either direction by means of a transit and illuminated rods, such as mining engineers use.

When the line has been fixed, the cross-bars may be removed for safe keeping until again required. Another method of adjusting the upper ends of the plumb-lines is shown in Fig. 6447, where A A is one of the cross-sills at the edge of the shaft, B B an iron plate fastened to the sill, and C a thin piece of metal may be moved sideways, in order to bring a V notch in its upper edge into the centre line. The notch being correctly fixed, the plumb-line E may be passed through it, and the direction at the foot of the shaft obtained as before. The plumbs should be suspended in a vessel of water, in order to check the vibrations; and every care should be taken to keep the wires from being jarred during the operation. When the tunnel is upon a curve the line may be laid off from a tangent established as above. Levels may be transferred from the top to the bottom of the shaft by a series of wires, fastened together like a surveyor's chain, the links being 8 or 10 ft. long, the whole length having been correctly ascertained.

6447.



Surveying and Levelling the Line.—The surveys and levels required for preparing the contract plans for a line of railway, do not differ in any material point from those necessary for other purposes. The method of executing them is described in Surveying and Levelling. The peculiarity of the survey for a railway is with the length. If the survey be made after the staking out of the line, the surveyor has the advantage of possessing an accurately-measured base line, and his operations are confined to connecting his triangles, which are seldom of any magnitude, with this base line. A distance of about 400 ft. on each side of the centre line will be found sufficient for the lateral extent of the survey. Particular attention should be paid to all boundaries, both public and private, and to those points at which the railway crosses under or over a road, river, or another line.

Cuttings and Embankments.—The earthworks of a railway comprise the cuttings from which earth has been excavated, and the embankments which have been formed by raising material on the natural surface. So far as is possible the engineer endeavours to place his cuttings and embankments so that the soil excavated from the one shall be used up, and shall be sufficient for the other; in which case the labour expended on the earthworks is applied in redistributing the material along the line. If the volume of the embankment is in excess, it becomes necessary to seek materials in side cuttings, or, if the cuttings are in excess, to form spoil banks, both of which being useless for purposes of the railway, involve a waste of labour, and sometimes of land. The cuttings and embankments must also, as far as possible, be so alternated that the earth from the former can be deposited in the latter without necessitating its transport to excessive distances. Yet again, in effecting the distribution of the earth derived from the cuttings to the embankments, the engineer must endeavour to render the labour of transport a minimum, both by depositing the earth from the cutting on the nearest accessible portion of embankment, and by avoiding the crossing of the routes by which the earth is led to the bank.

To secure the permanent stability of the superstructure, the earthworks must be carefully considered with reference to materials, form, and drainage. They should be of stable material, of liberal width, of easy slopes, and ample drainage.

The width required for a railway consists of the width of gauge, the widths of the rail-heads, and the side spaces. For a double line of way, also the middle space, or 6 ft.

The width outside the rails, or width of side spaces, is usually 4 to 5 ft., and that of the middle space between two lines of way, 5 ft. 6 in. to 6 ft. 6 in.

Hence for the whole width necessary for a railway, we get;—

Single Line of Way.

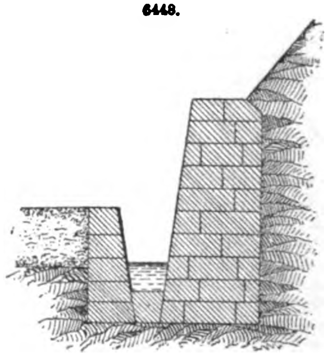
	European Narrow-gauge.				Indian.	
	From		To			
	ft.	in.	ft.	in.	ft.	in.
Gauge	4	8½	4	8½	5	6
Two rail-heads ..	0	5	0	5	0	5
Two side spaces ..	7	1½	9	10½	8	0
Width of ballast ..	12	3	15	0	13	11

Double Line of Way.

	European Narrow-gauge.				Indian.	
	From		To			
	ft.	in.	ft.	in.	ft.	in.
Two widths of gauge ..	9	5	9	5	11	0
Four rail-heads	0	10	0	10	0	10
Middle space	5	6	6	6	6	0
Two side spaces	7	3	10	3	8	0
Width of ballast ..	23	0	27	0	25	10

In addition to the width necessary for ballast, there is ordinarily left on each side of the ballast a horizontal bench, which increases the total width required on earthworks by 2 or 3 ft. in cuttings, and 4 or 5 ft. on embankments. In cuttings, a further width is required for side drains, which may be 1 ft. or 18 in. wide at bottom, with slope of 1 to 1.

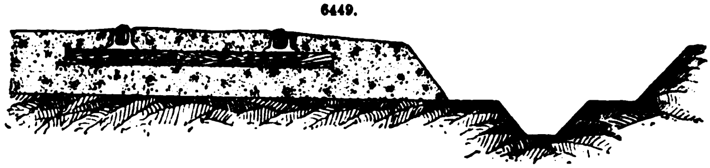
6448.



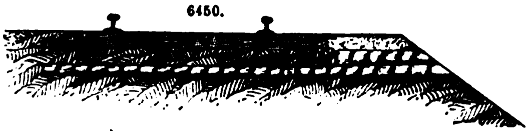
It is advisable to form a small bench between the drain and the face of the cutting, to catch falling débris and prevent its clogging the ditch. But, on the other hand, if the cutting is a deep one and it is desirable to economize labour in cutting or land, the width at formation level may be reduced by building a dwarf wall as in Fig. 6448, which supports the ballast on one side and the toe of the slope on the other.

Cross-section of the Line.—Composed as earthworks generally are, of comparatively impermeable materials, their surface is altogether unsuitable for the direct support of the permanent way. To bed the sleepers properly there must be provided a material of great frictional stability, of considerable hardness and compressive strength, easily permeable by water, and capable of resisting disintegration, either by water or frost. For this purpose a layer of broken stone, or gravel, is most suitable, or, if nothing better is obtainable, a layer of clean sand or burnt brick clay. The form given to this layer of ballast varies in different circumstances. Generally, in England and France, it is simply laid on the surface of the earthworks, which have been dressed to a convex surface to throw off the water, and a bench is left on each side, Fig. 6449. Sometimes, on German lines, the ballast covers the entire width of embankments at formation level, Fig. 6450. More generally, on Swiss and German lines, the ballast is economized by being laid in a trench, Fig. 6451. As ballast is often an expensive item in the cost of construction of a line, the economy in this respect is important. This last method of laying the line also permits some reduction of the total width of the line at formation level. But, on the other hand, the cross-drains require to be numerous, say about 9 to 12 ft. apart, and it is doubtful whether even in that case the drainage is quite as effectual as on the English system.

6449.



6450.



6451.

The ballast is laid in two layers; the lower layer, on which the stability of the superstructure depends, should have a thickness of 9 to 12 in. for broken stone or gravel, if on a tolerably permeable substratum, and of 12 to 18 in. if the substratum is humid. If the ballast is sand, a depth of 18 in. to 24 in. will be required for the lower layer. The upper layer of the ballast, or boxing, used for packing round the sleepers should have a thickness of 6 to 9 in., and its quality is not of quite so great importance as that of the lower layer.

The cross-section in Fig. 6451 is used in Russia with sand ballast, and in Switzerland with broken stone ballast. The quantity of ballast required, after deducting space occupied by sleepers, is about 65 cub. ft. a yard for the cross-section, Fig. 6449, and 41 cub. ft. a yard for that shown in Fig. 6451.

The older method of prosecuting cuttings was to work forwards on the whole face of the cutting, which was profiled to the required slopes as it proceeded. This method is, however, too slow for extensive railway cuttings, and the plan generally adopted is to run a gullet, or vertical-sided trench, through the cutting by working at the face, and then to work sideways from the gullet, widening the trench in successive benches. The benches are about 8 ft. apart vertically.

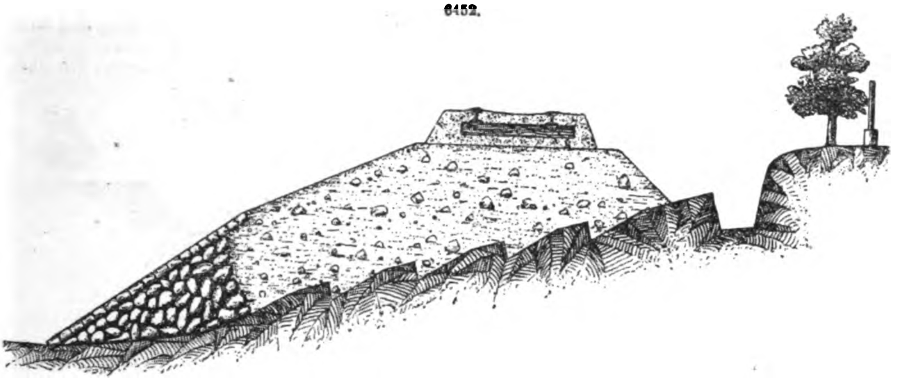
Embankments are executed in two ways, either by spreading over the whole area of the embankment successive horizontal layers, or by raising the embankment at once to the required height at one end, and carrying it forwards by tipping material over the advancing extremity. When constructed in thin horizontal layers the material is consolidated as the work proceeds,

by the passage of the barrows or carts, and also by atmospheric agencies. A much more complete consolidation of the material is secured than by the other method, and hence, this mode of construction is invariably adopted for reservoir embankments. This method, however, is too slow and too costly to be generally used on railways, except for filling in behind retaining walls and abutments.

When an embankment is carried forward from one end, the earth may be tipped directly over the end so as to fall in a series of thin layers all inclined at the angle of repose; or a bridge of discharge may be formed at the end of the embankment from which the earth wagons deposit the soil, and which is carried forward from time to time as the successive layers reach the height of the embankment. By this latter method greater solidity in the bank is secured, and the ultimate settlement is less. But it is only economically applicable to very large embankments, and is less often used than the simpler method. Occasionally embankments have been raised to only half their full height at first, and when this portion has settled, a second portion has been carried forwards over the first, completing the bank.

On sidelong ground, the seat of an embankment requires to be carefully cut in steps, or benches, that the soil of the bank may be bonded into that on which it rests, and that water may not percolate between the old surface and the earthwork raised on it, Fig. 6452. The destruction of

6452.



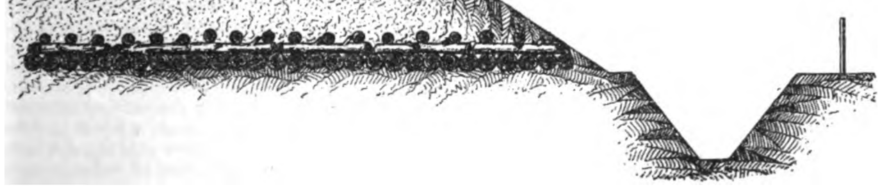
several embankments has been due to neglect of this precaution. For the same reason, the turf and vegetable débris should be carefully removed from the seat of the embankment, before its construction is commenced.

During the construction of the bank the settlement should be carefully studied, and in order to prevent the serious evil of having to patch the slopes, the height and width of the bank should be made rather greater than will ultimately be required, so that the surfaces may be trimmed down to their proper dimensions, after a great part of the settlement has already been accomplished. The amount of settlement varies in different cases, from $\frac{1}{12}$ to $\frac{1}{5}$ of the total height. The ultimate settlement of embankments of gravel or chalk does not require more than two or three years, but clay embankments may, in some cases, continue to shrink for ten years.

It has already been pointed out that when the seat of a bank is compressible, or of feeble stability, the bank constructed upon it will not stand at its natural angle of slope, however good the materials of which it is composed. When an engineer has to carry an embankment over marshy ground his first object must be to consolidate the foundation of his bank, as much as possible, by drainage. For that purpose large open drains, parallel to the axis of the line, may be first excavated. Sometimes he may be able to remove the compressible foundation and replace it by better materials. At others, he may consolidate it by fascines, or by piles. Sometimes he may use for his embankment very light materials, as, for instance, was done at Chat Moss, where, after first covering the yielding surface with hurdles, the bank was formed of dry peat. Again, large open pits may be formed and filled with compact clay.

Fig. 6453 shows one of many embankments on marshy ground on the 3 ft. 6 in. gauge railways

6453.



of Norway. In this case the subsoil has first been dried by large side drains; then on the seat of the bank fir-tree trunks have been spread lengthwise and crosswise, and over them the smaller

branches of the fir trees. Finally, the embankment has been carried forward over the consolidated foundation thus prepared.

Near important works of construction the earthworks should be made with great care, and of the best and most permeable materials. The backs of arches should be well punned with earth, before earth is tipped over them.

When a cutting exceeds 40 ft. in depth, it is advisable to form a bench 6 ft. in width at about two-thirds the height. This receives the surface water from the higher lands, which may be conveyed to the side drains at the bottom of the slopes by earthen pipes, wooden trunks, or stone drains, Fig. 6458.

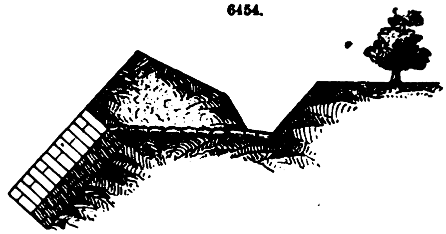
To permit the flow of surface water the formation level should be dressed in slopes of 1 in 35, from the centre line towards the sides. If this is not done the top of the bank is apt to become concave, and to retain the rainfall in the ballast.

Fig. 6452 shows an embankment on sidelong ground, constructed of earth, of doubtful stability, the toe of which is formed of loose broken stone as a security against slipping.

Cuttings are sometimes 100 ft. deep, and embankments rise occasionally to an almost equal elevation. The Tring cutting of the London and Birmingham Railway averages 40, and is at parts 60 ft. deep. The New Cross cutting of the South-Eastern Railway is, at parts, 75 and 80 ft. deep; the Wynchborough cutting on the Edinburgh and Glasgow, though solid rock, varies from 25 to 60 ft. in depth, and is 4 miles in length. It is succeeded by an embankment 1¼ mile long and 60 ft. high. The Olive Mount cutting of the Liverpool and Manchester Railway is 2 miles long and at parts 100 ft. deep; and on the Newcastle and Carlisle there is a cutting 110 ft. in depth; but when the depth exceeds 60 ft. it is generally more economical to tunnel.

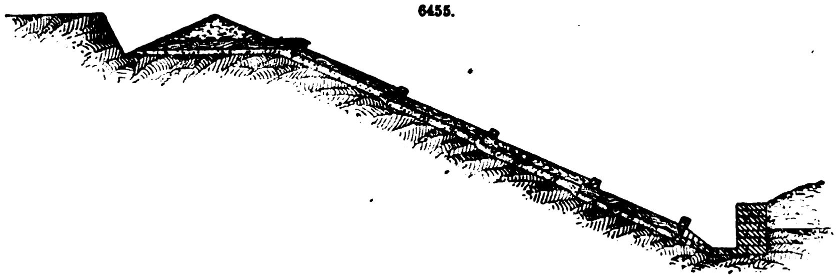
Drainage of Cuttings.—In all cases it is desirable to establish at the top of the slope of a cutting, on the side towards which the surface waters flow, a drain with an alternate rise and fall of about 1 in 100, communicating at its lowest points, by means of open drains, or earthen pipes, with the side drains at the bottom of the cutting, Fig. 6454; and care must be taken to prevent, by puddling or otherwise, the infiltration of the water from the drain at the top of the slope, into the soil forming the side of the cutting.

6454.



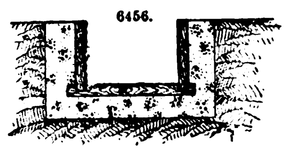
Figs. 6455, 6456, show another method of

6455.



effecting the protection of the slopes from the flow of surface water. A water-course is formed at the top of the slopes, and from this open drains, formed of planks bedded in hydraulic mortar, conduct the surface waters to the side drains at the foot of the slopes. The wooden trunks are simply nailed together in 6-ft. lengths, and the bed of mortar is about 3 in. thick. The ditch at the bottom of the slope is roughly pitched with dry stone.

6456.



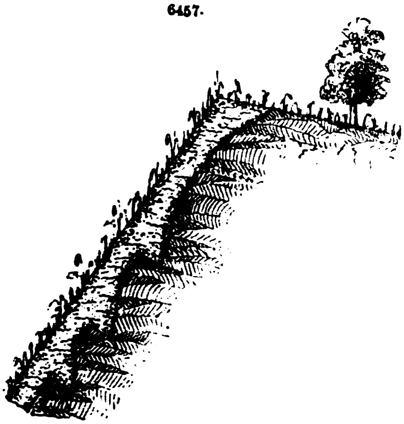
When a cutting is opened through clay or other soil liable to become slippery when wet, it is especially necessary to protect the surface of the slopes from cracking under the drying influence of the sun and wind, and then receiving through the sun-cracks surface water, which destroys their stability. For this purpose they must be covered with a coating more permeable and more stable than themselves, and suitable for vegetation. This coating may be 10 or 12 in. thick, and in order that it may be bonded into the slopes, they should be cut in benches of about 6 in. deep, with an inclination longitudinally of about 1 in 7. The coating should be spread in layers and well rammed, Figs. 6457, 6458.

The foot of the slope wetted by the waters of the side drains should, in this case, be protected by dry stone pitching, or with a brick drain, Fig. 6459.

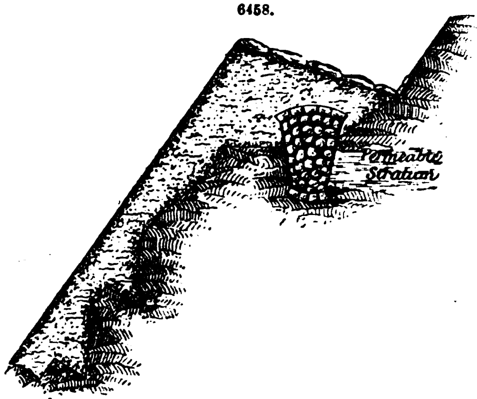
The worst cases with which the engineer has to deal are those in which the cutting intersects strata alternately permeable and impermeable; where, for instance, a permeable layer is found between strata of clay; and the danger in this case is increased if on either side the strata dip towards the cutting. In such a case there may be at times a considerable flow of water from the permeable stratum, which if not drained off may destroy the stability of the mass. Or there may be land springs at various points, which if undetected when the cutting is in course of construction, can only be discovered with great difficulty afterwards, and remain a permanent but hidden source

of danger. The engineer must therefore watch carefully during the excavation for evidences of permeable or water-bearing strata or springs; it will be of service to take note of the appearance of

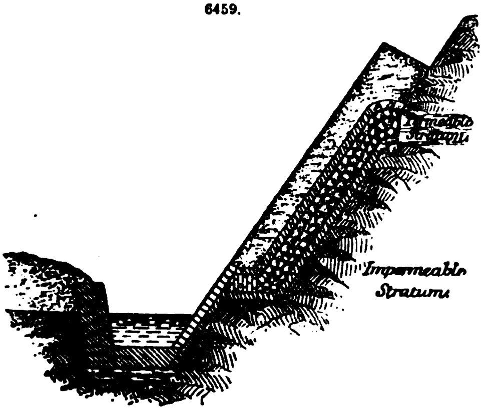
6457.



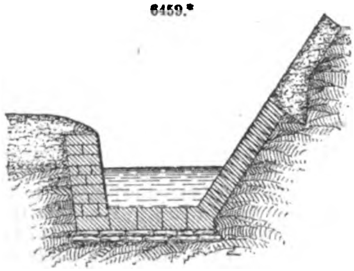
6458.



6459.



6459.*



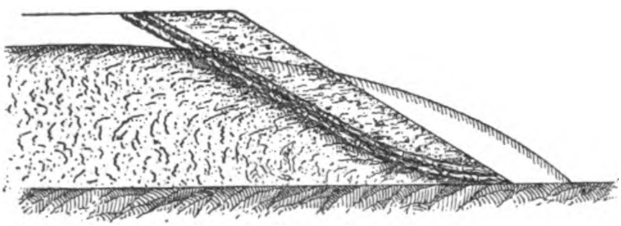
the soil at sunrise, or even to sprinkle dry sand over strata suspected of containing springs, the more readily to detect the humidity. Further, when once springs have been detected in any well-marked stratum, it may be concluded that similar springs may, in wet seasons, be found wherever that stratum is found. In those cases the object to be attained is to drain off as rapidly as possible the waters of the permeable stratum, and prevent their flowing over the surface of the slopes or filtering into the less permeable and more slippery strata. When such a stratum has been discovered a longitudinal drain must be formed, Fig. 6458, along its line of outcrop, with rise and fall alternately of 1 in 100. The bottom of the drain may be formed of bricks or stones set in cement, the drain may then be filled with broken stone or clean gravel, and covered with reversed turf, flags, or tiles, to prevent the penetration of soil. A foot in width at the bottom of the drain will generally suffice, the sides rising with a batter of 1 in 7. The low points of this longitudinal drain must be connected by transverse drains, Fig. 6459, with the side drains at the foot of the slopes. The slope may then be protected by a coating of permeable soil, as already described. Sometimes it is desirable to drain the whole surface of a slippery slope with small drain-pipes carried horizontally at distances of about 15 ft. apart, with alternate rise and fall, and connected at their low points with pipes running down the slope to the side drains.

The drain-pipes should be buried to a moderate depth, and the open cuttings in which they are laid may be filled with broken stone and covered with earth.

Drainage of Embankments.—To secure the permanent stability of embankments similar precautions must be taken to prevent the percolation of water, as in the case of cuttings. At the foot of the slope on the higher side towards which the surface waters flow, a water-course or drain should be constructed, to convey the water away from the seat of the bank, Figs. 6460, 6461. In the construction of embankments the engineer will reject, if necessary, soil of bad quality obtained from cuttings, and supply its place by more stable material obtained by side cutting. Sometimes, in spite of precautions, the embankments slip during or after construction. Such slips may arise either from the deficient stability of the foundation on which the embankment is placed, or from the use of defective material in the construction of the bank, or from the flow of water over the *talus*. The precautions to be taken on marshy unstable ground have already been mentioned. If, in spite of precautions, an embankment slips during construction, the whole of the slipped earth must be

removed, and the bank again filled up with the same or better materials, carefully rammed in horizontal layers.

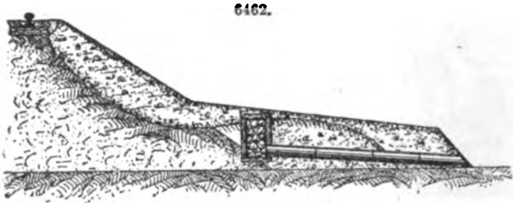
6460.



6461.

Fig. 6462 is a section of part of the embankment of Pourtieres repaired after a slip. The materials of the slip were first removed and then relaid in horizontal layers. But in doing so drains were formed of fascines filled with gravel, to dry the materials of the bank. Similar drains were formed in the part of the bank which had not given way, to prevent a repetition of the disaster. At the embankment of Morcerf it was found necessary to construct a longitudinal filter, or drain, of broken stone, surrounded by matting, to prevent the penetration of earth. In some parts of the embankment two of these drains were formed, communicating with each other. The slipped part of the bank was attached by successive cuttings, carried at right angles to the line as far as the position of the original foot of the slope; then a trench was opened parallel to the line of way, in which drain-pipes were placed, covered by a filter of broken stone, enclosed in matting. Finally, there was constructed at the foot of the slope a cavalier of good soil, built up in horizontal layers, well rammed, Fig. 6461. When it is impossible to remove the slipped portion of a bank which has given way, a new bank must be formed over the slipped portion of sand or gravel, and especial care must be taken that its drainage is complete, and maintained in working order. If the drains should be injured by subsequent settlement, new drains should be at once formed.

6462.



If embankments are liable to be washed by inundation waters or otherwise, it will be of the utmost importance to construct them of materials the stability of which is little changed by humidity. Further, they should be carefully turfed, and for some distance above and below the level which the waters are likely to attain they should be protected from erosion by a pitching of stone. Usually the best protection from atmospheric degradation of the slopes of cuttings and embankments, is afforded by covering them with a layer of vegetable earth, to a depth of 6 or 8 in., and sowing them with grass, clover, or lucerne. When the slope is wanting in stability, couch-grass has sometimes been employed, the advantage being that its roots penetrate to a depth of 2 or 3 ft. On friable soils of chalk or sand, and especially on steep declivities, neither the sowing of herbaceous plants nor turfing succeeds, because of the surface. Then recourse must be had to the sowing or planting out of ligneous plants, the roots of which penetrate more deeply, such plants being chosen as are found to thrive on mountains. Of these, those principally employed on the Continent are the juniper, berberry, sea buckthorn, saintfoin and lucerne, acacia, ash, willow, birch, and maple. The conifers are prejudicial, from the blowing of their leaves upon the rails, causing slipping of the wheels of the locomotives.

Calculating Contents of Cuttings and Embankments.—Under the article Embankments will be found several methods for effecting these calculations. There are numerous tables for facilitating them, by Bidder, Macneil, Bashforth, Barlow, and other engineers. Putting H and H_1 for the two heights of the cutting, B for the ratio of the slopes, and L for the length, we have by the prismoidal formula for C the contents in cubic feet, $C = L\left\{\frac{B(H + H_1)}{2} + \frac{R}{3}(H^2 + H_1^2 + H H_1)\right\}$. As C is usually required in cubic yards, and L in feet, we have

$$C = L\left\{\frac{B(H + H_1)}{54} + \frac{R}{81}(H^2 + H_1^2 + H H_1)\right\}.$$

There are two approximate methods of ascertaining the contents of a prismoidal block. The first is the method of mean heights, by taking it as if the section in the middle were the average section; and the second, or method of mean areas, by taking half the sum of the end areas to be the average section. The errors belonging to each of these methods are seen at once, by comparing the content as given by it with the true quantity. The method of mean heights gives a content of $L\left\{B\frac{H + H'}{2} + \left\{\frac{H + H'}{2}\right\}^2 R\right\}$, and an error of $\left(-\frac{(H - H')^2}{12}\right)L$. The method of mean areas gives a content of $L\left\{B\frac{H + H'}{2} + \frac{(H^2 + H'_2)}{2}R\right\}$ and an error of $\left(+\frac{(H - H')^2}{6}\right)L$. So that one method gives an error in excess, the other an error on the other side, and one error is double the amount of the other.

There is another way of expressing the true content, it is;—to the sum of the end areas add four times the middle area, and multiply the sum by one-sixth of the length. In cuttings it will constantly occur that the contents are not all rock or all clay, but will be partly rock and partly clay. In this case the rock can be taken out as above, and the clay taken out in blocks the same way as before, with this exception, that each block will have a different base. The base of each block of clay cutting must be taken as a mean of the bases at each end, or, what is the same thing, a mean of the widths of the top of the rock cutting at those points. This method of getting the quantity of the clay is not strictly accurate; the true content of a block of this kind is given by this formula, $Q = L\left(\frac{B(2H + H') + B'(2H' + H)}{6} + \frac{R}{3}(H'^2 + H H')\right)$, where B is the base of the clay at the end at which H is the height, and B' the base, and H' the height at the other.

The error introduced by the approximative method is $+ \frac{(B - B')(H - H')}{12} L$. It is to be remarked that this error is to some extent compensating, sometimes being in excess and sometimes the other way. The approximative method gives too much, if at the same time $B > B'$ and $H > H'$, and too little if $B > B'$ and $H < H'$.

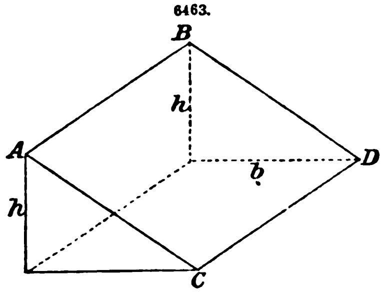
Cases will occur when none of the rules above given apply, namely, when the ground is so uneven as to require cross-sections. The best thing to be done in this case is to take the mean of the two areas of the two cross-sections and multiply it by the length between them, and reduce to yards.

In those instances in which heavy cuttings occur without any corresponding embankments in which to dispose of the material, it will be found economical to employ dwarf walls. There will be a particular height of cutting at which the cost of the walls is equivalent to the cost of the excavation avoided, which may be thus found. Let H be the height of the cutting, B the base of the cutting, R the ratio of the slopes, H_1 the height of the walls, B_1 the width between the walls, P the price a cube yard of excavation, and P_1 the price a yard run of the dwarf wall. Then we have $(H - H_1) 2 R H_1 + R H_1^2 + H(B - B_1) = \frac{18 P_1}{P}$; from which we deduce $H = \frac{18 P_1 + R H_1^2 P}{P(2 R H_1 + B - B_1)}$. When the height of the excavation exceeds H, it is more economical to introduce dwarf walls. These are usually built plumb on the back and face. When they are about a certain height, they are battered on the face, and then become retaining walls in the strict sense of the term. On the above calculation the walls are supposed to be perpendicular on the face, and if they should be battered, the difference with respect to the excavation is too trifling to deserve notice. Whenever the material of the cutting is clay, and has to be run to spoil, the walls should always be substituted so soon as the limiting height of excavation is reached.

Borings, and Soiling Slopes.—At certain distances along the line borings should always be made to ascertain what amount of rock may be fairly expected, and the section should show a line of demarcation between the earth and the rock. Borings require to be made very carefully, as the ground is exceedingly deceptive, and any subsequent rectification is a fruitful source of dispute between companies and contractors.

It frequently happens during the progress of the works of a line of railway in which the cuttings and embankments are of considerable magnitude, that due precaution is not taken to reserve in their vicinity a sufficient amount of material for soiling or top-dressing the slopes, and the consequence is, that either they are not covered with the proper quantity, or the contractor is obliged to bring the soil from some distance along the line, or procure it elsewhere at more than the ordinary expense. The quantity requisite for the different cuttings and embankments depends principally on the depths and heights, and varies also as the ground is more or less sidelong. The simplest case which can occur is when the height is constant for a given length of the longitudinal section of the line, and when the cross-sections also for that distance are level. This is shown in Fig. 6463, which represents one of the slopes of either a cutting or embankment, the other being supposed to be precisely similar. As the soil is always of a uniform depth, its quantity is taken out in superficial yards. In Fig. 6463 let A B or C D = L = the length on the longitudinal section, let h = the height constant for the length L, and let S be the number of superficial yards of soil required for both slopes, all other dimensions being in feet; then $S = \frac{2 \text{ area of } ABCD}{9}$; but, from the figure, area of $ABCD = AC \times L$, and $S = \frac{2\,AC \times L}{9}$. A C is the length of the slope, and is unknown, but supposing b to be constant, as it always is in practice, A C depends on h. Now by construction $AC^2 = h^2 + b^2$, and substituting for b its value $R \times h$, R being ratio of slope,

6463.



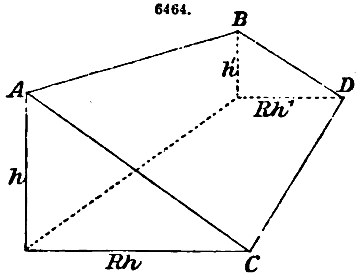
$$AC^2 = h^2 + R^2 h^2 = h^2(1 + R^2) \text{ and } AC = h\sqrt{(1 + R^2)}.$$

Putting this value of A C in the equation for S, we obtain $S = \frac{2h\sqrt{(1 + R^2)} \times L}{9}$. R is almost universally $= \frac{3}{2}$ and $\sqrt{(1 + R^2)} = \frac{\sqrt{13}}{2}$, which gives us by substitution in the above equation

$S = \frac{2\,h \times L}{9} \times \frac{\sqrt{13}}{2}$. Multiplying out and reducing we obtain $S = h \times L \times 0{\cdot}4$, which is a general formula applicable to any height and distance. If we make L = 1 chain = 100 ft., the formula becomes very simple, for $S = 40\,h$; if L = the statute chain = 66 ft., $S = 26{\cdot}4\,h$.

Another case which is more frequently met with, and the solution of which is of greater practical utility, is when the heights at the two ends of the given length of the longitudinal section are unequal, as is represented in Fig. 6464; h and h' are the two heights, and the remainder of the notation is the same as that employed above.

6464.



As before $S = \frac{2 \text{ area of } A\,B\,C\,D}{9}$; area of $A\,B\,C\,D = L \times \left(\frac{A\,C + B\,D}{2}\right)$. From above $A\,C = h\sqrt{(1 + R^2)}$, and by similar reasoning $B\,D = h'\sqrt{(1 + R^2)}$; therefore area of $A\,B\,C\,D = \frac{L}{2} \times \{\,h\sqrt{(1 + R^2)} + h'\sqrt{(1 - R^2)}\,\}$,

which gives us $S = \frac{L}{9}\{\,(h + h')\sqrt{(1 + R^2)}\,\}$. Substituting for the expression $\sqrt{(1 + R^2)}$ its equivalent $\frac{\sqrt{13}}{2}$ and reducing, we obtain finally $S = L\,(h + h') \times 0{\cdot}2$; if L = 100 ft., then $S = (h + h') \times 20$; if L = 66 ft., then $S = (h + h')\,13{\cdot}2$.

It is evident that by making $h = h'$, the first three equations became identical with the last three, but a separate proof and demonstration is given, not only to preserve uniformity in the different examples under investigation, but because it may serve to render the subject clearer to many persons, especially those perusing it for the first time. These equations will be found particularly useful to those engaged in making the estimates for contract work of a line of railway, as the ground may generally be considered level between any two ordinates on the longitudinal section, which are at the distance of one chain from one another; unless it is exceedingly rough and irregular, and even then any deficiency or excess in so inexpensive an item as trimming and soiling slopes is not of much consequence.

All the foregoing formulæ have been calculated on the supposition that the cross-sections of the ground are level, or, in other words, that the quantity of soil required for one slope is the same as that which is required for the other.

It is manifest that, in sidelong ground, this would not be the case, and in some instances, where the difference of the heights on the two sides is great, it might be necessary to allow for it in taking out the quantity. This might be accomplished in two ways, either by applying any of the above equations, which suit the particular case in question, to each respective side of the cutting or embankment, and dividing the result by 2; or by making use of the following formula. Let H, H′, h, h', be the four different heights, then from Fig. 6464 and the equations the number of superficial yards of one slope $= L\,(h + h') \times 0{\cdot}1$, and of the other $= L\,(H + H')\,0{\cdot}1$, and total number $S = L\,(H + H' + h + h')\,0{\cdot}1$, which can be simplified in a corresponding manner for the different values of L = 100 or 66 ft.

In any instance in which the sidelong ground continued to slope uniformly in the same direction across the line for a considerable distance, it might be found quite as advantageous, if not more so, to take out each side of the line separately, and to employ the former instead of the latter method.

In the preliminary estimates of a line of railway for parliamentary purposes, trimming and soiling slopes is so insignificant an item that it is hardly ever taken into account; but in a case where the cuttings and embankments were excessive both in number and magnitude, and where a close and vigorous opposition would render an equally close and accurate estimate requisite, it would be prudent to ascertain its amount either by direct calculation, or allow a sum for it, suggested by experience. In such calculations, it would be convenient to take out a whole cutting or embankment at one operation; and quite sufficiently accurate to consider the cross-sections of the ground level, and consequently the area of the two slopes equal to one another.

The following formula is general for any length L and number of heights $h, h_1\, h_2\, h_3 \ldots h_n$, which for simplicity's sake may be taken at equal distances; let x = number of heights taken, then $S = \frac{L}{x - 1}(h + 2\,h_1 + 2\,h_2 + 2\,h_3 + \ldots + h_n)\,0{\cdot}2$. If L be taken an even number of hundred feet, as it may be in such examples, and let N = number of 100-ft. lengths, and allowing one penny a superficial yard, we obtain, by putting M for the amount in pounds,

$$M = \frac{N}{12\,(x - 1)}(h + 2\,h_1 + 2\,h_2 + 2\,h_3 + \ldots + h_n).$$

It will be at once seen, that when the length admits of it, this substitution can be applied to all the other formulæ, and the price therefore obtained at once from the values of the lengths and heights or depths.

Masonry, Brickwork, and Ironwork.—In those lines in which timber is not employed as a constructive material, the permanent structures are built of one of the three enumerated, or of a combination of them. Where stone can be procured in the neighbourhood of a good quality, suitable for the purpose, its use is only limited by the considerations of time, and the possibility of employing the

arch form instead of the horizontal in bridges and viaducts. Having once determined the description of material to be used in the building of the permanent works on the line, the next step is to consider the structures themselves.

Bridges.—Every information on these structures will be found in article Bridges, and we shall therefore confine ourselves to noticing a few points in them most intimately connected with our subject. Bridges are divided into two principal classes—bridges on the square, and bridges on the skew. See OBLIQUE ARCH. Bridges on the skew are rarely built now of masonry or brickwork. The time consumed in cutting the stones to the proper twist and other considerations have virtually put an end to the construction of stone skew bridges, even when the material is at hand. Skew bridges are sometimes built with stone abutments and the arch turned in brick; when neatly done the structure looks very well. Unless the span is of very considerable dimensions the building of a bridge on the square is a very simple matter, provided the foundations are good and proper supervision exercised over the materials and workmanship. The consideration of headway generally leads to the adoption of iron bridges, even where stone is plentiful. In the case of over-bridges the reduction of the heights may be of great importance as reducing the quantity of the embankment, or shortening the length of the approach. In under-bridges it may be of still greater importance, allowing a reduction in the height of an embankment, which should perhaps have to be made from side cutting. Iron bridges may also be adopted for another reason, on account of any insecurity in the foundations that would render some slight settlement in the abutments probable. An arch might be seriously damaged by a settlement that would in no way affect an iron superstructure.

In designing a bridge all the parts of the drawing must be carried on together; neither plan nor elevation can be finished by themselves without having the sections drawn, or as vividly impressed on the mind as if they were drawn.

The footings in over-bridges should be at least 1 ft. below formation level, to enable the water-tables or side drains of the railway to be carried continuously through the bridge. The projection of a footing depends on the material employed; every front stone in a footing course should be at least as much imbedded in the work as it is exposed, else the footings lose their value, which is to spread the pressure; hence the projection mentioned above may be increased, or must be diminished, according to circumstances. If a greater width of foundation is thought necessary, it must be gained by increasing the number of the footings, and not their width.

The height of abutment, span, and rise of arch are known quantities. The radius of the circle of which the arch is a segment is given by the equation $R = \frac{r^2 + s^2}{2r}$, where R = radius, r the rise, and s the semi-span of the arch. In segmental arches of moderate span, the extrados is struck from the same centre as the intrados. The thicknesses of the arch and of the abutments are subjects of theoretical investigations, but practically depend on previous examples. It is possible to determine the width of an abutment that will just keep the arch in equilibrium, but this has to be modified by a coefficient of safety, in itself very variable, so that the value of the theoretical rule is practically lost. The haunching is usually carried up at the back in a plumb-line with the abutment, terminating at a point 1 ft. or more, below the soffit of the crown of the arch, and raked from that in a line tangent to the extrados, to allow water to run freely off. Steps are sometimes introduced to lighten the haunching.

The counterforts are built at the back of the abutments, and are usually plumb at the back. Sometimes they are raked off in a line with the haunching, and sometimes are stopped lower down. Their object is to help the abutment to withstand the thrust of the arch. There is no use in founding counterforts as low as the abutments when the bridge is in cutting, they should go down to a good foundation for themselves. They may or may not have footings. The puddle is usually shown 6 in. deep, and should extend over the counterforts. Asphalte is often used instead of clay puddle.

Iron bridges are either of cast or of wrought iron, the former being now confined to the cases of carrying roads over railways, where it is an object to save the height of the approaches, or for other reasons.

Wrought-iron bridges to carry the railway over roads are of two kinds, one where the railway is supported by under-girders, one under each rail, or by side and cross girders. The latter, if for double line, are of two kinds, firstly, with two side girders, with at least 25 ft. 6 in. clear space between them and carrying both roads, or a set of three girders, with a single road between each pair.

These girders, in ordinary cases, are either lattice or plate girders, and may be in each case either single or box girders. The names explain their nature. For rules for finding the strength of each different part of a lattice or plate girder, see article Materials of Construction, Strength of.

On the plan of every bridge should be shown at least three views, one of the superstructure complete, one of the bridge, or part of it, with the parapets, string-course, coping of wings, and newel-caps removed, and a third of the foundations. In designing iron bridges the various parts should as much as possible be duplicates of each other, so as to diminish to a minimum the number of templets required. It must be kept in view that all structures consist of two items, materials and workmanship, and it is quite possible to make the latter so expensive as to double the cost. All bending, cranking, forging, and welding of iron should be avoided, especially when the pieces are of large dimensions. It adds little or nothing to the contract price to bend a piece of angle iron 4 or 5 ft. in length, but when that length is increased to 15 or 16 ft. the contractor will at once require an extra price for workmanship. As an example may be quoted the case of an ordinary lattice bridge, in which the flanges are horizontal and all the bars in the web of the same length, and a bowstring girder in which the upper flange is bent, and all the bars in the web of a different size. The difference in the contract price of these two examples of bridge girders will reach to 30s. more a ton. It is not to be argued from this that bowstring girders are not to be used, but that they

are to be used only when the circumstances of the case justify the additional expenditure. In large spans the bowstring girder is an economical type of railway bridge.

Tunnelling.—The greatest intensity of pressure in a buried archway occurs usually in its sides, at the ends of the shorter diameter of the oval intrados; and that intensity is given approximately by the following equation.

Let x_1 be the depth of the shorter diameter below the surface of the ground, b' the half-span of the archway, a' its rise, t the thickness of its side, w the weight of a cubic foot of the earth; then the greatest pressure, in lbs. on the square foot, is $q = \frac{w\{x_1(b'+t) - 0 \cdot 8\, a'\, b'\}}{t}$; and this should not exceed the resistance of the material to crushing, divided by a proper factor of safety.

It appears that in the brickwork of various existing tunnels the factor of safety is as low as four. This is sufficient because of the steadiness of the load, but in buried archways exposed to shocks, like those of culverts under high embankments, the factor of safety should be greater, say from eight to ten.

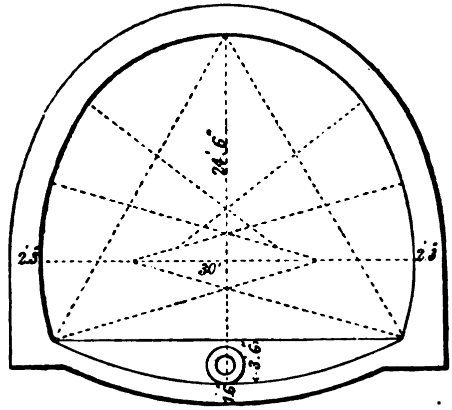
How small soever the load may be, there is a certain minimum thickness for an underground archway, for determining which the following empirical rule, exactly similar to that for finding the depth of the keystone of an arch, has been deduced from practical examples. The rise and half-span being denoted as before by a' and b', compute approximately the longest radius of curvature of the intrados by the formula $r = \frac{a'\,2}{b^1}$; then least thickness t in feet $= \sqrt{0 \cdot 12\, r}$.

This is applicable where the ground is of the finest and safest kind. In soft and slippery materials the thickness ranges from one and a half to double that given by the equation; that is to say, from $\sqrt{0 \cdot 27 r}$ to $\sqrt{0 \cdot 48 r}$. The thickness of an underground arch at the crown may be made less than at the sides in the ratio b' a'; but the more common practice is to make it uniform.

Tunnels are driven through hills and spurs of mountains to avoid very deep cutting. At the best they are sources of large expenditure, and should, if possible, be avoided. When tunnels are cut through rock of a solid and durable character the roof supports itself; but when in loose or easily decomposed rock, or in earth, an artificial arched lining becomes necessary. Such lining is generally made of brick, especially the arched part, on account of the greater ease of handling and laying brick than stone in so confined a situation. Among the difficulties attendant upon the construction of tunnels are the want of light, air, and drainage. As tunnels generally occur upon summits, or on the approach to them, the latter requirement may be met by the introduction of a light gradient. The lower end upon the gradient will drain itself; the upper end will require pumps; an occasional well being sunk as low as the contemplated road-bed, or a little lower, to collect the water. Short tunnels may be built by working from the ends only; but as a very limited number of hands can be employed on so small a working face as the heading affords, when the length becomes considerable, shafts are sunk from the surface to formation, and from the bottom of these, headings are run in both directions. This operation involves a large expenditure, as all draining, ventilating, and removal of materials must be effected through the shaft.

In cutting a tunnel in rock, a small heading, 6 or 8 ft. square, is first taken out by one gang of men, while a larger gang follows in the rear, enlarging the work to the full size, and putting in the masonry where such is required. The rapidity with which the small opening can be worked is the measure of the progress of the whole; as the enlarging and lining allows the employment of more hands than the limited dimensions of the heading can accommodate. After a tunnel has been driven about 500 ft. artificial ventilation becomes necessary. This is accomplished by the ordinary mining expedients, drawing off the bad air by the draught of a chimney with a fire at the bottom, or forcing fresh air in. If the shaft is made in the bottom of a depression, in order to reduce its length, it may be necessary to provide for the surface drainage in such a locality; regard should be paid, in laying out the work, to this requirement. The general practice in England has been to multiply the number of shafts; and in some cases, tunnels have been cut entirely through from the shaft headings, before the approaches were taken out. In tunnels made through loose material, it has frequently been the practice to commence by running forward two small headings, in which the side walls are built, before the remainder of the section is excavated. In other cases, the upper part of the tunnel has been opened first, and the arch built; the space for the side walls being next excavated, and the arch propped by timbers until the walls are built up to connect with it. When the gradient descends from a shaft, or at the end of a tunnel where the gradient descends into the work, and the water follows the operations in a troublesome manner, the heading may be commenced at the bottom of the intended section, and run along, on a slight ascent, until it reaches the top, when a pit may be sunk to the level of the floor, and the heading may be started again, and the ascent commenced anew. The size and proportions of tunnels may be illustrated best by reference to examples. The Box Tunnel, Fig. 6465, is between Chippenham and Bath, upon the Great Western Railway, in England. It is 3200 yds. in length, 30 ft. wide at the widest, and 24½ ft.

6465.



high above the roadway. Nearly half of it passes through the Bath oolite limestone, and the other half through clay. It is straight, and rises from one end to the other upon a gradient of 1 in 100, or 52·8 ft. a mile. For about three-fourths of a mile it has no lining; the remainder is finished with side walls of the oolite and an arch of brick. There are seven shafts, having an internal diameter of 25 ft., widened to 30 ft. where they intersect the tunnel. The deepest shaft is about 300 ft. They are lined with brick.

The Brislington Tunnel, upon the same railway, 1100 yds. long, has nearly the same section as the Box, and is made in a very hard rock. This short tunnel has nine shafts; in order to hasten the work, a driftway, 7 ft. wide and 8 ft. high, made in eight months, was run the whole length before the enlarging was commenced. The whole work was done from the inside, on account of the heavy cuts at the ends. The enlarging of the heading was carried on at all of the nine shafts; but the materials were raised up by only three, which were about 110 ft. deep and 15 ft. internal diameter.

The Woodhead Tunnel, upon the Manchester, Sheffield, and Lincolnshire Railway, near Manchester, is 3 miles 26 ft. long, 14 ft. 4 in. wide at the level of the rails, and 18 ft. 3 in. high, from the rails to the under side of the arch. The sides are vertical, and there is no invert. The road is provided with a small drain, next the wall upon each side. A second tunnel, of precisely the same dimensions, was afterwards built parallel with it, separated by a longitudinal pier, 21 ft. thick, through which are twenty-one arched openings, about 12 ft. wide, connecting the two. The first tunnel was made with shafts, about 10 ft. in diameter, upon one side of the centre line, which now descends into the middle of the connecting arches. In making the second tunnel the shafts were not used; but the side walls were first cut through, and openings made horizontally into the line of the new tunnel, all of the material being brought by cross roads to the finished line, and run out in cars.

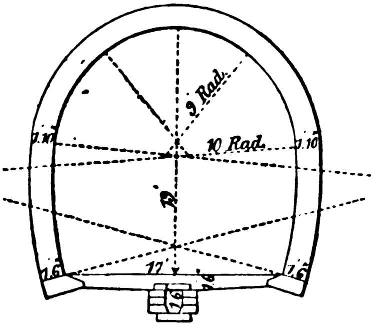
The Kilsby Tunnel, upon the London and Birmingham Railway (London and North-Western), is about 2400 yds. long, with a section of 27 × 23½ ft. It is cut through clay and sand, and occupied about four years in its construction. It was intended to make the brick lining 18 in. thick, but this was increased, for the most part, to 27 in. The whole was laid in Roman cement. During the construction of this work an immense quicksand was encountered, out of which water was pumped for eight months, night and day, at the rate of 1800 gallons a minute. The large shaft, 60 ft. in diameter and 132 ft. deep, was completed in a year; its walls are perpendicular and 3 ft. thick; the bricks being laid in Roman cement. This immense shaft, as well as the second, which was 30 ft. less in depth, was built from the top downwards, by excavating for small portions of the wall at a time, from 6 to 12 ft. long and 10 ft. deep. The whole number of bricks used in this tunnel was 36,000,000. The cost, which was estimated at 90,000*l.*, reached the sum of 350,000*l.*

The Netherton Tunnel, upon a branch of the Birmingham Canal, was completed in 1858. It is 3036 yds. in length, 27 ft. wide, and 24 ft. 4 in. high. The brickwork for the lining was generally 1 ft. 10½ in. thick in the side walls and arch, and 1 ft. 1½ in. in the invert; the thickness being increased where the shafts join the arch, and also in some places where the ground was bad. At several points the invert was pressed up from beneath, in some cases as much as 5 in., the bricks remaining unbroken. In one place, where the bottom was forced up 8 in. at the centre, and the bricks were crushed, the invert was cut out for a length of 130 ft., and rebuilt 1 ft. 10 in. thick. This was done in short pieces—about 6 ft.—at a time, the side walls being carefully strutted. In rebuilding a portion of this invert, 49 ft. in length, the versed sine was increased to 2 ft. 6 in.

There were seventeen shafts, 9 ft. in diameter, seven of which were left permanently open, and lined with brickwork 9 in. thick. This brickwork was built upon an oak curb 9 × 3 in., from beneath which the earth was excavated, the curb being temporarily propped until underpinned by the brickwork brought up from the second curb below. The greatest depth of the shafts was 344 ft., and the least 66 ft. The average rate of progress a day of twenty-four hours, from the commencement to the completion of each shaft, was 2 ft.; but counting only the days upon which work was actually done, 3 ft. 4 in. The material was chiefly blue marl. The size of the heading was 5 × 3 ft., the bottom being level with the top of the invert.

The Almondsbury Tunnel, near Bristol, upon the Bristol and South Wales Junction Railway, Fig. 6466, is 1221 yds. long, 18 ft. 6 in. wide at the widest part, 17 ft. wide at the road-bed, and 19 ft. high. It was built for a single track; the whole work being done by means of the shafts, of which there were five; the deepest being 144, and the least 67 ft.

6466.

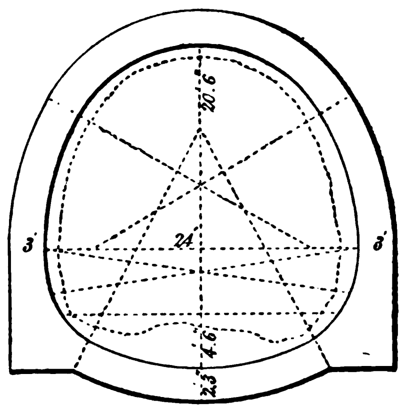


The Sydenham Tunnel, on the London, Chatham, and Dover Railway, is 2100 yds. long, and is made through the London clay. It had seven shafts, varying from 50 to 186 ft. in depth, and 9 ft. internal diameter. Two only of these shafts were intended to be left open permanently. The clay in which this work was executed, through yielding freely to the pick, afterwards swelled and crushed the masonry. The shafts were made 9 ft. in diameter, but were afterwards pressed in, so as to be hardly more than 6. The headings were 4 × 6 ft., and were run forward at the top, and not the bottom, of the excavation. The original section is shown in Fig. 6467. But the swelling of the clay so forced in the masonry that 6780 cub. yds. of the side wall and 2065 yds. of the invert had to be rebuilt. At the foot of one of the shafts, 120 ft. deep, which was the worst place, the tunnel was at first lined with eight rings of bricks, making a thickness of 36 in. This was cut out and replaced, first by ten, and again by twelve rings of brickwork, or 4 ft. 6 in. of thickness; and even some of the last had to be replaced.

The shafts had at first a lining of brick 9 in. thick; but this was so pressed in, and the diameter

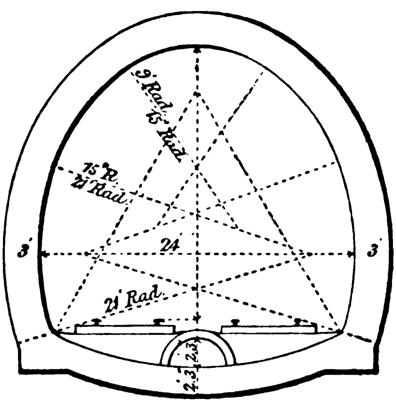
so reduced, as to require a new lining 18 in. in thickness. This action of the clay begins very soon after the excavation is made; if it is not noticed within two months, it is no longer feared. The action at the top of the arch is slight, the principal effect being on the invert, which rises first at the centre and afterwards at the sides. The dotted line in the figure shows the altered shape of the original section. The form was afterwards changed; the first step being to lower the invert, which showed such a tendency to rise, and the next to lower the arch and flatten it at the top, until finally the section of the tunnel was almost a circle, the thickness of the lining above the road-bed being 4 ft. 6 in., and that of the invert 3 ft. Preference was given in this work to lime-mortar over cement, as it hardens more slowly, and receives the first pressure gradually, by which the bricks do not break so readily.

6467.

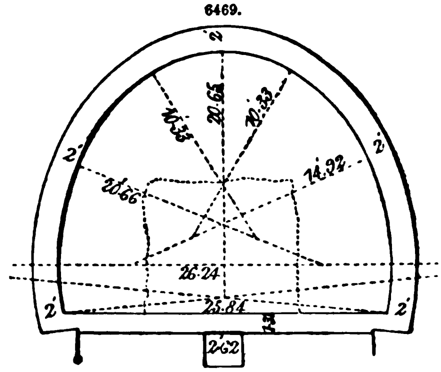


The Bletchingly and Saltwood tunnels are between London and Dover, upon the South-Eastern Railway. The Bletchingly is 24 ft. wide, and 21 ft. from the top of the rail to the under side of the crown of the arch; the versed sine of the invert being 3 ft., and the form as in Fig. 6468. The length is 3972 ft.; the tunnel being inclined at the rate of 3 ft. in a mile. The material through which it is cut is blue

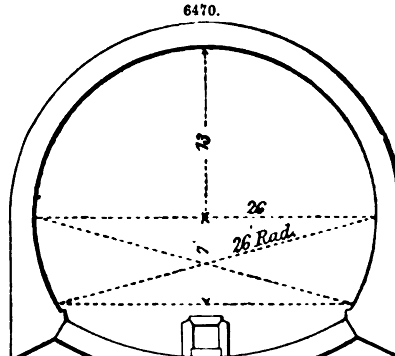
6468.



6469.



6470.



clay. The thickness of the lining varies from 1 ft. 10½ in. to 3 ft., according to the ground. The time occupied in the construction was 626 days.

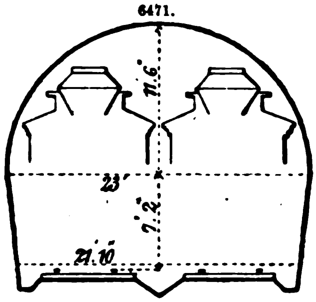
The Hauenstein Tunnel, between Basle and Olten, upon the Central Swiss Railroad, is 2729 yds. long, of which 1970 yds. were cut from one end. This work passes through limestone, sandstone, and shale. It is made for a double track, being 26 ft. wide, 20 ft. high above the rails, and of the form shown in Fig. 6469. In some places it has an invert and at others none. The line is straight and the gradient uniform, rising 1 in 38, or 139 ft. in a mile. The masonry is limestone, no bricks being used. The heading was about 10 ft. square, and run forwards at the bottom; but on account of the water that followed the descending gradient, it was not kept parallel with the intended road-bed, but was run from the bottom up towards the roof, within the limits of the section. From the heading enlargements were made at different places, to get additional working faces.

The Mont Cenis Tunnel, which was completed in the summer of 1871, is, without doubt, the largest work of this kind ever undertaken. It is 7 miles 1044 yds. long, and of the section Fig. 6470. The grade rises at the rate of 117·22 ft. a mile, or 444·90 ft. in all, from the French end to the centre; and falls, for the purpose of drainage, at the rate of 2·64 ft. a mile, or 10·04 ft. in all, from the centre to the Italian end; thus making the southern portal 435 ft. higher than the northern. The tunnel is lined with masonry throughout, but with no invert, a covered drain being made in the centre. The side walls are of stone, laid in regular courses, and the arch upon the Italian side in brick. Recesses, large enough for several men, are made at frequent intervals, and at every 550 yds. a tool chamber, 10 or 12 ft. square, is provided. The side and arch masonry is about 2 ft. thick, though varying at different points. The tunnel has no shafts, being at the

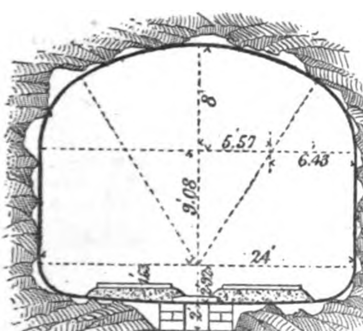
deepest more than a mile beneath the summit. The drilling at this great work was done by machinery, the tools being arranged upon a carriage, and driven by a most ingenious application of compressed air, which, after furnishing the required power, escaped, and served to ventilate the heading. The progress of the tunnel was such as to give a total advance of 30,068 ft. in twelve years, or 2506 ft. in a year, or 209 ft. a month, or 104·5 ft. a month at each working face.

Fig. 6471, which is a section of the Spruce Creek Tunnel, on the Pennsylvania Railroad, shows how little room there is to spare when two trains occupy the metals; the width in this case is 23 ft. at the widest part, the gauge 4 ft. 9 in., and the width between rails 6 ft. The Alleghany, or Gallitzin Tunnel, upon the same road, has a width of 24 ft.

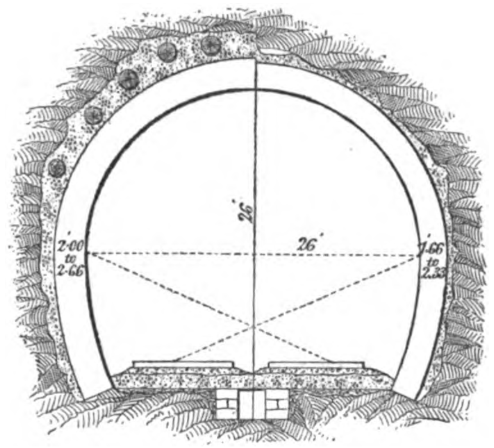
6471.



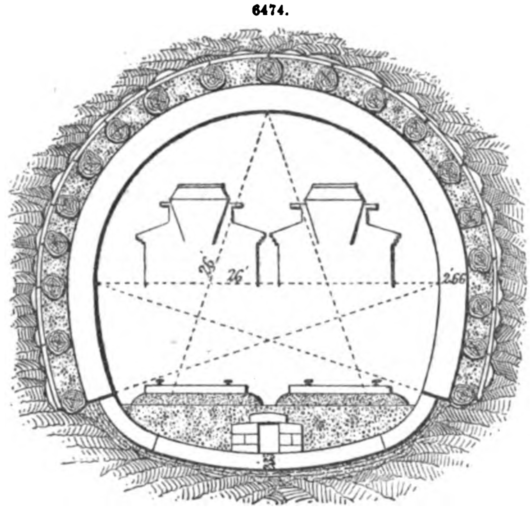
6472.



6473.



6474.



The Hoosac Tunnel in process of construction (1873) beneath the mountain of the same name in Western Massachusetts, is 25,031 ft., or 4¾ miles long. It is to be of the form and dimensions shown in Figs. 6472 to 6474, Fig. 6472 representing the section in the solid rock where a lining is not required. The right-hand half of Fig. 6473 shows a half section of the tunnel arched; the left-hand half of the same figure shows a half section with the lining and with a preliminary timber support to the roof, to protect the workmen until the brick arch is completed. Fig. 6474 is a section of the lining where an invert is required. The gradient rises at the rate of 26$\frac{40}{100}$ ft. a mile from each end to the centre. Shaft No. 1 is 1498 ft. from the western end, and has a section of 6 × 6, and a depth of 215 ft. Shaft No. 2 is 2183 ft. from the western end, and has a section of 13 × 6, and a depth of 277 ft. These shafts were sunk for the purpose of drainage, before the heading had been driven through from the west end. The west shaft, 2447 ft. from the western end, is 14 × 8 ft., and 318 ft. deep, and is the working shaft where the material excavated eastward was hoisted. The central shaft, about midway between the ends of the tunnel, is elliptical in section, 27 ft. in diameter along the line of the road, 15 ft. in diameter across the road, and 1030 ft. deep. The Hoosac Mountain, on the line of the tunnel, rises to a height of 2500 ft. above the sea, and about 1800 ft. above the road. There is a double summit, and the central shaft is placed in the intermediate depression.

The general character of the rock at the eastern end and at the central shaft is mica slate with quartz; and at the west shaft a hard quartzite. The first 2000 ft. at the western end, being through a rapidly decomposing material, required to be arched with brick. The headings have been driven, and much of the enlarging done, by the machine known as the Burleigh Rock Drill. These drills are in each heading mounted upon two carriages, standing side by side, with a space of about 6 ft.

between them. Each carriage supports five drills; but seldom more than four, eight in all, are in motion at one time. They make from 180 to 260 strokes a minute, with a pressure of 60 lbs. an inch.

When a blast is to be fired, these carriages are run back out of the way. The power for working the drills, compressed air, is the same as that used at the Mont Cenis Tunnel.

At the eastern end of the work a dam across the Deerfield River gives a head of 21 ft., which works four turbine-wheels, each wheel working four air-cylinders. The air, compressed to a tension of about 65 lbs. an inch, is conveyed into the tunnel through two 8-in. cast-iron pipes; and experience shows that it loses little or nothing of its force in the transit.

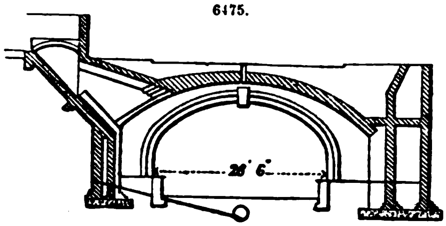
When the gauge at the compressors shows 65 lbs., that at the heading shows 63 lbs. At the eastern end the excavation of the heading is effected by ordinary cannon powder, and the enlarging by nitro-glycerine. At the western end, where the rock is very much harder, nitro-glycerine is almost wholly used; and the central shaft has been sunk altogether with the same material. About 6000 lbs. of this new explosive, and 250 kegs, of 25 lbs. each, of powder, are used every month. The explosion is effected wholly by electricity, every charge in a blast, sometimes as many as thirty, being discharged simultaneously.

The underground work is carried on in three shifts daily, eight hours being a day's work; thus the tunnelling goes on unceasingly through the twenty-four hours, Sunday only excepted.

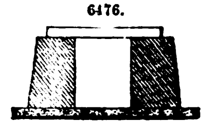
The preceding sections are all drawn to the same scale, and thus show the correct relative size of the various tunnels referred to.

The most modern system of tunnelling is that employed on the London Metropolitan Underground Railways. Fig. 6475 is a cross-section of the general type of tunnel adopted. The dimensions vary a little in some parts, but, as a rule, are as follows. The span in the clear of the arch is 28 ft. 6 in. The thickness of the arch, 2 ft. 5 in., or equal to six rings, and backed by concrete spandrils. The height from the level of the rails to the crown of the arch is usually 16 ft. 6 in., but on some parts of the line it is increased to 18 ft. 9 in. Every portion of the length of the tunnel is provided with a drain, which is carried underground in the centre between the two lines of rails; and every area and pocket and basin, or funnel-shaped collector of land and surface water at the back of the walls or over the asphalte covering of the tunnel, has its down-pipe, and its connection carefully made.

6475.

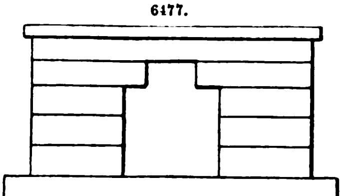


6476.

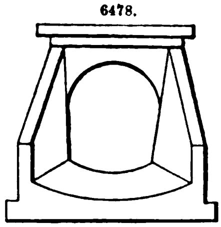


Culverts.—The simplest form for a culvert carrying a small stream beneath an embankment is shown Fig. 6476. It consists of two side walls and a covering of flags, and forms a very economical structure, when flat stones can be readily procured. Care should be taken that the water-way of all culverts is in excess of their actual requirements, and no water should ever be allowed to find its way behind or underneath the masonry. The following dimensions given in Table III. will serve as good approximate guides for general use. Under high embankments the depth of the flag may be increased at the centre of the length of the culvert, when the weight is a maximum. A face wall may be built to a culvert when appearance is an object, as in Fig. 6477, and for larger streams wing walls, Fig. 6478, are usually built. A cross-section would have the appearance represented in

6477.



6478.



6479.

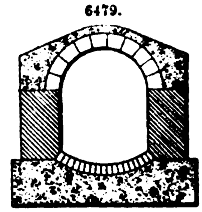


Fig. 6479. Culverts are classed according to their different spans, and when small in size are usually called drains. A common practice with the English Drainage Commissioners is to place the invert of the culvert about 5 ft. below the natural surface of the ground. On this assumption, the depth of filling over any culvert in an embankment may be thus obtained. Let D = the required depth, H the height of the culvert between the invert and the top, and H_1 the height of the embankment. Then we have $D = H_1 - (H - 5)$. The length of the culvert, putting R for the ratio of the slopes, B for width of formation level, and L for the length, will be $L = (H_1 - H + 5)\,2\,R + B$. If the width of the formation level be that of an ordinary single line, equal to 18 ft., and the ratio of slopes $1\frac{1}{2}$ to 1, the length in yards of the culvert will be given by the equation

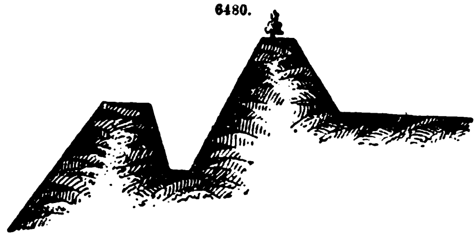
$$L = 2\,R\,(H^1 - H + 5) + B + C.$$

TABLE III.

Area.	Opening.	Side Wall.	Depth of Flag.	Length of Flag.
4	2 × 2	2 × 2	12	5
9	3 × 3	3 × 2½	16	6
16	4 × 4	4 × 3	20	7
25	5 × 5	5 × 3½	22	8
36	6 × 6	6 × 4	24	9

Fencing.—In some countries the line is not fenced at all, but in all those in which the property on either side is held by private landowners, fencing of some sort is indispensable. The readiest made description of fence, when labour is cheap, is that commonly used in Ireland, and consists of a ditch and mound as shown in Fig. 6480. The material excavated from the ditch is thrown into the mound, and a quickset hedge planted along the top. After the lapse of some time this makes a good fence, but it requires in the interim a considerable amount of repair. It is also very liable to be trodden down by cattle, and people walking on the top of it. The common timber post and rail fence is well known, and there are besides an almost infinite variety of iron fencing. When the line passes through a private demesne, iron fencing of an ornamental description is frequently employed. Perhaps the best fence that can be put up along a line is the dry stone wall. If well built, and the stones well bonded together, with a rough coping set in mortar, edgeways, it forms an excellent protection against the trespass of both man and beast.

6480.



Metalling and Pitching.—See ROADS.

Ballasting and Boxing.—The material most commonly used for ballast is gravel, or broken stone; and when these cannot be obtained, burnt clay, cinders, slag, broken brick, shells, and even small coal have been made use of. Whatever material is employed, it should be hard and clean, and capable of binding into a solid mass, to prevent it being washed away from under the rails and sleepers. The common width for ballast on the standard gauge is 14 ft. for a single and 26 ft. for a double line of way. The depth is about 1 ft. 9 in. to 2 ft. Boxing is the upper 6 in. or so of the ballast, and must not be quite so coarse as the lower stratum. The quantity of ballast to the mile required for different depths and widths is given in Table IV.

TABLE IV.

Depth in inches.	Cubic Yards of Ballast a Mile. Slopes 1 to 1. Width on top for					
	Single Line.			Double Line.		
	10 feet.	11 feet.	12 feet.	21 feet.	22 feet.	23 feet.
16	2955	3216	3477	5823	6084	6344
18	3375	3667	3960	6600	6894	7187
20	3802	4128	4454	7387	7713	8039
22	4242	4600	4959	8186	8544	8903
24	4693	5084	5475	8996	9387	9775

Laying Permanent Way.—The laying of the permanent way is but too often left almost entirely to the platelayers. This is a serious mistake. Proper centre stakes should be put in, especially in the curved portions of the line, and particular care paid to the super-elevation or cant of the outer rail. The tendency for a carriage to leave the metal when running round a curve results from three causes. 1st. The centrifugal force; 2nd. The parallelism of the axles; and 3rd. The slip of the wheels. Put V for the velocity of a train in feet a second, R for the radius of the curve, F for the centrifugal force, and W for its weight. Then the following proportion prevails $F : W :: \frac{V^2}{32 \cdot 2\ R} : 1$. This is the ratio which the cant or elevation of the outer above the inner rail of the curved line of rails must bear to the gauge or transverse distance between the rails. Let V be the speed in miles an hour, G the gauge, and C the cant for the centrifugal force, then $C = G \times \frac{V^2}{15\ R}$ nearly. One half the cant should be given by raising the outer rail above the level of the centre line, and the other half by depressing the inner rail. It is obvious the cant cannot be adjusted for all speeds, and the safest plan is to adopt it nearly to the maximum speed. If an average speed of 40 miles an hour be assumed as the datum, the cant for different gauges and different curves will be found in Table V. The tendency to leave the line, which arises from the axles being parallel instead of radiating from the centre of the curve, cannot well be distinguished from that due to the slipping of the wheels, which is thus caused;—The outer rail of any curve is

longer than the inner rail in the proportion of the radius added to the gauge radius. While the inner wheel rolls over a given arc of the inner rail, the outer wheel, if it be of the same diameter with the inner wheels, has to slip over a distance equal to the difference of the lengths of the rails. This causes an additional resistance to the advance of the outer wheel of each pair of wheels, tending to make the front end of the carriage swerve outwards. The taper or coning of the wheels was designed to prevent this tendency, by causing the outer wheel to run on a portion of its tire of larger diameter than that on which the inner wheel runs at the same time. The coning of the wheels has the disadvantage of increasing the oscillation or sideward lurching of the trains when running on a straight line. This tendency to swerve may be corrected in cylindrical wheels by means of an additional cant, which throws the larger proportion of the weight on the inner rail. The additional cant required for that purpose was determined experimentally by D. Rankine and W. J. M. Rankine, for carriages moving on a narrow-gauge line at speeds of from 3 to 12 miles an hour, and found to be independent of the velocity and inversely proportional to the radius of the curve. Putting C for the additional cant in inches, we have $C = \frac{7200}{R}$, in which R is the radius of the curve in feet. The use of bogeys or axle-boxes sliding in curved guides renders this additional cant unnecessary.

TABLE V.

Gauge.	Cant for Centrifugal Force in inches.
4 ft. $8\frac{1}{2}$ in.	6000 ÷ radius in feet.
5 „ 3 „	6680 ÷ „ „
6 „ 0 „	7680 ÷ „ „
7 „ 0 „	8960 ÷ „ „

Expansion of Rails.—The ends of rails if laid at a low temperature must not be placed in contact, since wrought iron expands 0·0000068 of its length for each degree Fahr. A change of temperature of 130° will cause the following elongation in rails of different length. A rail 15 ft. in length will become 15·0133 ft.; if 18 ft., it will be 18·0159 ft.; and if 20 ft., 20·0177 ft. If we assume the maximum temperature at which rails may be placed in contact to be 100°, then the distances to be left between the joints at different temperatures are given in Table VI. Rails which have been laid in contact in cold weather, have been thrown out of line and out of level more than a foot by the powerful force of expansion, which may be said to be irresistible. In fishing all joints, the holes in the chairs must be longer than those in the rails, in order to allow of the proper expansive motion. Serious accidents have happened through the neglect of this simple precaution, even on lines upon which the rails weighed over 80 lbs. a yard, and were well secured by fish-joints.

TABLE VI.

Temperature.	Distances in inches.	Temperature.	Distances in inches.	Temperature.	Distances in inches.
°		°		°	
90	0·016	40	0·114	0	..
80	0·049	30	0·131	10	0·179
70	0·065	20	0·147	20	0·196
60	0·082	10	0·163	30	0·212
50	0·098				

Specification.—A specification or detailed description of the various works to be carried out is always attached to a contract. It would require considerable detail to treat this subject fully, but we may briefly mention a few prominent points in connection with it. The description of the commencement and end of the work should be very accurately and minutely stated. The clauses also should be very distinct which relate to the time allowed, the mode of payment, the testing and delivery of materials, and the penalties provided in each separate instance. Attention to these points not only materially contributes to the rapid and efficient execution of a contract, but avoids all future arbitration and litigation. A good specification should be the joint production of both engineering and legal ability, neither unduly sacrificing the one feature to the other. While proper tests should always be stipulated for, yet if they are carried to an extreme degree, as frequently happens, they defeat their own object. When it becomes impossible to carry out certain unreasonable demands, the alternative is to evade them as much as possible; and it must always be borne in mind that the more stringent the demand, the greater the difficulty in enforcing it.

See ARCH. BALLAST. BRIDGES. CONSTRUCTION. PERMANENT WAY. SIGNALS.

RATCHET-WHEEL. FR., *Roue à rochet;* GER., *Sperrrad;* ITAL., *Ruota a nottolino;* SPAN., *Rueda de trinquete.*

A circular wheel having angular teeth, by which it may be moved forward, as by a lever and catch, or pawl, and into which the pawl may drop to prevent the wheel from running back. See MECHANICAL MOVEMENTS.

REACTION. FR., *Réaction;* GER., *Reaction;* ITAL., *Reazione;* SPAN., *Reaccion.*

In mechanics, reaction is the force which a body subjected to the action of a force from another body exerts upon that body in the opposite direction.

REACTION-WHEEL. FR., *Roue à réaction;* GER., *Reactionsrad;* ITAL., *Ruota a reazione;* SPAN., *Rueda de reaccion.*

See BARKER'S MILL.

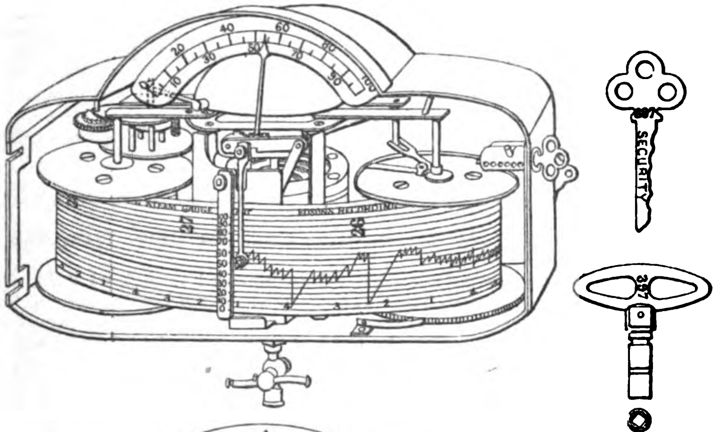
REAMER. Fr., *Alésoir;* Ger., *Reibahle;* Ital., *Allargatore;* Span., *Avellanador.*

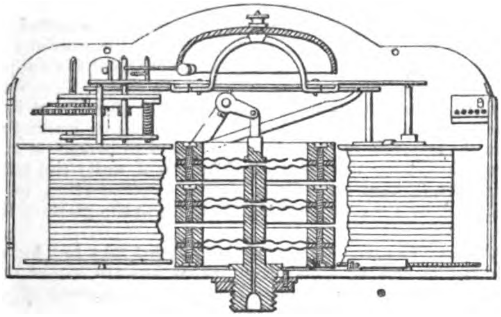
Reamer or Rimer is a tool used to enlarge a hole in a bevelled form.

RECORDING PRESSURE-GAUGE. Fr., *Manomètre enregistrant;* Ger., *Manometer zum Anzeigen von Dampfdruck;* Ital., *Piezografo;* Span., *Manómetro automator.*

The objects of a recording steam-pressure gauge are to secure a true record of all pressures and variations of the same for reference, either in the interest of science or in investigations before coroners' and other juries, and for inspection by insurers, proprietors of manufactories, steamers, stationary engines, and locomotives, to ascertain at any time the past as well as the present strain or pressure sustained; also whether the employés are attentive to their duties and uniform in feeding the fuel and water, or whether they are careless, irregular, or incompetent, and therefore untrustworthy in the discharge of such important duties as surround the generation and use of steam, whether at high or low pressure. These objects are well attained in M. B. Edson's recording gauge, Figs. 6481 to 6483.

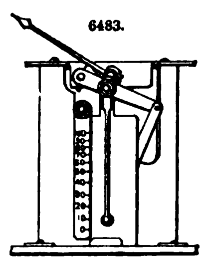
6481.





6482.

6483.



The springs consist of a series of circular elastic chambers; they are composed of thin circular steel discs, with corrugations, each pair forming a chamber by means of a flat brass or composition ring interposed between their outer edges, and having two compressing rings, one above and one under the discs, the whole being secured firmly together by screws, so as to be steam and air tight. A thin flat packing of foil or of sheet rubber is interposed for packing between the discs and the rings, and the discs, the rings, the couplings, and other parts are electro-plated with nickel to prevent oxidation, and thus preserve their accuracy for a long time. These chambers are connected together by hollow connections or couplings secured to the centres of the discs around an opening, and they are provided with alternate male and female screw threads, so as to be joined together in a series, the joints being steam and air tight. The lowest chamber is secured to the bed-plate, and is provided with a coupling, by which connection is made through a suitable pipe with a boiler or other vessel in which the fluid under pressure is generated. The upper chamber has on the top plate or spring a short, fixed, slotted vertical stud. These chambers are surrounded by a suitable casing, which supports the bearing whereon the oscillating rack and other parts are fitted. This casing is secured to the bed-plate to prevent any variation in the working parts. Upon a bearing is a segmental rack oscillating vertically upon points, and having on its outer segmental periphery teeth which gear into a pinion fast upon the horizontal shaft, on the front end of which is fixed a large spur-wheel for operating the vertical rack that carries the spring pencil-holder. On the opposite end of the horizontal shaft a smaller spur-wheel is fixed to gear into and to operate a horizontal sliding rack which passes through slots in the frame at each end. Upon the side of this segmental rack is fixed an open rectangular frame or shoulder, within which is placed the sliding adjustable link, and which is made to slide towards or from the centre of oscillation of the segmental rack by means of the two adjusting screws at the opposite ends. A connecting rod is at its upper

end pivoted upon a pin fast in the link, and at its lower end is fastened by a pin to a stud. The use of the sliding link is to increase or diminish the extent of the oscillation of the segmental rack. A reservoir drum, upon which the paper chart is wound, has its bearings upon conical points at the centre of the drum heads, the lower being fixed in the bed-plate and the upper bearings being the ends of adjustable screws, which pass through the horizontal brackets. Upon the opposite side of the cylindrical casing is the receiving drum, which has its bearing at the bottom, similarly to the reservoir drum. These drums have each a narrow slot, behind which is fitted an eccentrically-flattened rod to clip and hold the paper chart. Around the edge of the top of the receiving drum is a raised rim making a hollow circular space, in which is placed a universal or constant pawl, which is centred upon the drum head, but moving horizontally upon the said bearing. The short arm of the pawl is so arranged that when the long arm is pushed from the centre it will slip around within the rim loosely, so as not to turn the drum; but the instant the long arm is drawn towards the rack, the short arm will impinge upon the rim, and thus cause the drum to rotate. The pawl-lever is operated by a fixed pin in the end of the horizontal rack. The paper for the charts is wound around the first drum, and is passed in front of the bearing upon the casing, and between the said bearing and the pencil-holder, passing thence to and around the receiving drum. The paper chart is ruled with horizontal lines, and figured on the drum from zero to 90 lbs. pressure. The chart may also have zigzag tracings, indicating fluctuations in pressure. In front of the cylindrical frame the vertically-sliding rack rests in frictionless bearings upon the frame; the teeth of the rack mesh closely into those of the spur-wheel, by which the rack is operated, and is made to carry the pencil-holder up or down as the pressure is increased or diminished.

REFRIGERATOR. FR., *Réfrigérant*; GER., *Kühlfass*; ITAL., *Refrigerante*; SPAN., *Refrigerante*.

See ICE MACHINE.

RESERVOIR. FR., *Réservoir*; GER., *Behälter*; ITAL., *Serbatoio*; SPAN., *Estanques*; *algibes*.

See WATER-WORKS.

RETAINING WALL. FR., *Mur de soutènement*; GER., *Stützmauer*; ITAL., *Muro di sostegno*; SPAN., *Muros de contencion*.

Retaining Walls are masonry structures designed to impound or support fluid, semifluid, or granular materials, and are employed under various forms in the construction of fortifications, reservoirs, docks, wharves, sea defences, and lines of inland communication. In these constructions they appear as revetments, dams, and weirs, dock and sea walls, piers, breast walls, and wing walls. A retaining wall is said to be surcharged when the bank it retains slopes backwards to a higher level than the top of the wall. The slope of the bank may be either equal to or less, but cannot be greater, than the angle of repose of the earth of the bank.

In determining the proportions of retaining walls, engineers have been guided by principles deduced from the practical data furnished to mathematicians by the experiments and constructions of successful builders, so that theory and practice have gone hand in hand in establishing the laws and rules which lead to economical and skilful design. The same mechanical laws apply to retaining walls equally with all masses of masonry pressed by oblique forces, and it is therefore convenient to treat the subject of their equilibrium under the distinct heads of—the stability of the wall; and the pressure or thrust of the material retained—the combination of the results leading to the determination of the proper dimensions of the profile of the wall. It is usual in investigations connected with these subjects to confine the calculations to some unit of length of wall; the unit, therefore, which will be adopted for uniform walls, that is, walls of constant cross-section, in this article, unless otherwise expressly stated, will be 1 ft., taken at right angles to the plane of the profile or cross-section of the wall.

Stability of the Wall.—A mass of masonry pressed by an oblique thrust may fail through heeling over in the direction in which the thrust acts, or it may slide bodily forward, either on its base or on some plane in its substance. It will hereafter be seen that the contingency of sliding may, under ordinary circumstances, be dismissed from the consideration; but the effect of the heeling tendency must be carefully investigated in all cases.

A wall, in most text-books on the stability of structures, is treated as if it were a homogeneous adamantine mass which could actually turn over round the outer angle of its base, as on a knife edge; but this, except in very small structures, is an impracticable, not to say impossible, assumption, for there can be no doubt that in large walls the masonry of the face would crush, and the mass disintegrate near the point of rupture, long before the wall could actually tilt.

The resultant of an oblique thrust in a mass resting on a horizontal base may be resolved into two components—the vertical, causing a vertical stress or pressure on the base; the horizontal, tending to push forward the mass. The resistance which the wall opposes to the effects of the former is called its statical stability; to the latter, its frictional stability.

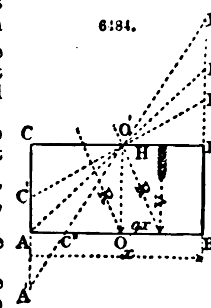
In retaining walls, the vertical stress is made up of the weight of the wall; and the vertical component, if any, of the thrust of the material retained by the wall; while the horizontal force is simply the horizontal component of the same thrust.

Dealing first with the statical as distinguished from the frictional stability of the wall, we find that when the resultant of all the forces acting on the mass passes through the centre of figure of its base, the vertical pressure is considered to be a stress distributed uniformly over the base; its amount at all points is equal and of a mean intensity, found by dividing the total vertical pressure by the area of the base. When, however, the resultant does not pass through the middle of the base, the centre of resistance, which is the point of application of the resultant in the base, will not coincide with the centre of figure of the base, and therefore the stress will increase in intensity on that side towards which the resultant deviates, according to a law which is, that the intensity is at any point proportional to the horizontal distance of the point along an axis in the direction of the thrust. This is the law of an uniformly varying stress. It is this increase of pressure on the edges of the base which tends to crush the materials of the wall, and cause failure long before the

resultant or centre of resistance can have reached the face of the structure. When the resultant passes outside the face, the pressure being unbalanced, the wall must heel. We will confine ourselves to the stability of walls independently of their foundations, although it is easily seen that the same principles may be applied to the resistance of the materials composing the foundations as well as to that of those of the wall. We shall therefore suppose our walls placed on secure foundations. Failure of foundations through excess of stress nevertheless must be guarded against as likely to occur in retaining walls—a notable instance of such failure being the Puentès dam in Spain, already referred to, Fig. 2248, in article Damming.

The diagram in Fig. 6484 represents the distribution both of an uniform and an uniformly varying stress. The rectangle A B C D represents the former; one of the other figures, contained by dotted lines, as C′A′, B D, the latter. Let A B be a plane forming the base of a wall, and let the resultant pass through the centre o. Erect a perpendicular $\overline{o\,o'}$, equal to the mean intensity of the vertical stress; and since the stress is uniformly distributed its amount at every point is equal, and the total stress is represented by the ideal rectangle A B C D.

6484.



But when the resultant does not pass through the centre o, since the total amount of the vertical stress cannot vary, its mean intensity must remain constant and equal to $\overline{o\,o'}$, and therefore, as it varies uniformly, lines drawn through o' will form ideal figures representing the total stress, the ordinates of which will represent the stress at any point.

The ordinate at the point B will give the maximum stress or pressure at the face of the wall.

It appears, therefore, that the mean stress increases towards B as the ordinates of a triangle such as O′ D D′, and decreases towards A as those of an equal and similar triangle D′ C C′.

When the deviation of the resultant from the centre of the base is one-sixth of the breadth of base, the ideal figure is a triangle, as A B D′, in which B D′, representing the maximum pressure, is double O O′, representing the mean pressure. When the deviation exceeds one-sixth the breadth of base, a portion of the stress, represented by the triangle A A′ C, becomes negative, and denotes a tension; but a tensile force being practically an element too uncertain to deal with in masonry may be neglected, thus constituting an element of safety, while it simplifies the investigation.

The conditions of the problem, it will be seen, however, entail the use of alternate formulæ for the maximum pressure; one when the deviation of the resultant from the middle of the base is less than, or equals one-sixth the breadth of base, the other when it is greater. Let p be the mean intensity of the pressure on the unit of surface of the base $= \dfrac{\text{vertical forces}}{\text{area of base}}$; p' the maximum intensity of the stress on the unit of surface; q the ratio of the deviation of the centre of resistance, from the middle of the base, to the breadth of base; x the breadth of base; then so long as the deviation is not greater than one-sixth, the relation of p' to p is

$$p' = p\,(1 + 6\,q), \qquad [1]$$

and when the deviation exceeds one-sixth,

$$p' = p\left(\frac{2}{3\,(\frac{1}{2} - q)}\right). \qquad [1\text{A}]$$

These formulæ are identical with those already given in the article Damming, the notation being adapted to that here given by making $\dfrac{l}{2} - v = q$.

The following Table of examples gives the ratios of p' to p for several values of q, calculated by the preceding formulæ;—

Table A.

For Values of q *less* than, or *equal* $\frac{1}{6}$th.

$q =$	$\frac{1}{12}$	$\frac{1}{11}$	$\frac{1}{10}$	$\frac{1}{9}$	$\frac{1}{8}$	$\frac{2}{15}$	$\frac{1}{7}$	$\frac{2}{13}$	$\frac{1}{6}$
$\frac{p'}{p} =$	$\frac{3}{2}$	$\frac{17}{11}$	$\frac{8}{5}$	$\frac{5}{3}$	$\frac{7}{4}$	$\frac{9}{5}$	$\frac{13}{7}$	$\frac{25}{13}$	2

For Values of q *greater* than $\frac{1}{6}$th.

$q =$	$\frac{2}{11}$	$\frac{1}{5}$	$\frac{2}{9}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
$\frac{p'}{p} =$	$\frac{15}{7}$	$\frac{20}{9}$	$\frac{12}{5}$	$\frac{8}{3}$	4	$\frac{16}{3}$	$\frac{32}{3}$	∞

We see from what has gone before that it is requisite for the safety of a wall that the deviation from the middle of the base of the centre of resistance—the point where the resultant cuts the base—must be limited.

If it should exceed one-half the breadth of base, the wall would overset; and if it should equal the half-breadth, the maximum pressure being infinitely great would require an infinite resistance to crushing in the materials of the wall. The limit therefore clearly is that the deviation shall not be such a fraction of the base as will cause the maximum pressure to exceed the safe resistance to crushing of any of the materials of the wall; or, if f be the safe resistance of the materials, that p' shall not be greater than f.

To determine the thickness of the wall so that this condition shall be fulfilled, we must seek values of p and q, on which p' depends, in terms of x.

We know that $p = \dfrac{\text{weight of wall + vertical component of the thrust at back}}{\text{area of base of wall}}$; therefore if W_1

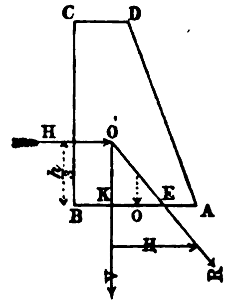
be the whole weight of the wall; w_1 the weight of a cubic foot of its substance; h the height of the wall; $\frac{1}{n}$ the fractional part which the area of its profile bears to the area of a rectangle of equal height and breadth; x the breadth of the base of the wall; H the horizontal; and V the vertical components of the thrust at the back of the wall; we have

$$p = \frac{W_1 + V}{x} = \frac{w_1 h}{n} + \frac{V}{x}. \qquad [2]$$

If $q\,x$ and $q'\,x$ be the horizontal deviations of the centre of resistance of the base, and of the centre of gravity of the profile from the middle of the base, we have in Fig. 6485 $q\,x = \mathrm{O\,E}$, $q'\,x = \mathrm{O\,K}$, and $\mathrm{K\,E} = q\,x \pm q'\,x$, the upper or lower sign being used according as the points K and E lie on the opposite or the same side of the middle of the base O; O′ K being the height of the centre of pressure equals $\frac{h}{3}$, therefore $\mathrm{O'K} : \mathrm{KE} :: \mathrm{V} : \mathrm{H}$, thus $\frac{h}{3} : (q \pm q')\,x :: \mathrm{V} : \mathrm{H}$, and hence we obtain

$$q = \frac{H\,h}{3\,V\,x} \mp q'. \qquad [3]$$

6485.



The following values of $\frac{1}{n}$ and q' are found for certain sections;—

Form	$\frac{1}{n}$,	q',
Rectangles and parallelograms ..	1,	$\frac{r\,h}{2\,x}$,
Triangles	$\frac{1}{2}$,	$\frac{r\,h}{3\,x} - \frac{1}{6}$,
Trapezoids	$\frac{x+t}{2\,x}$,	$\left(\frac{r\,h}{3} + \frac{t-x}{6}\right)\frac{x+2\,t}{x+t}$,

where $r\,h$ is the batter of the face of the wall, t the thickness of the wall at top.

By substituting in equations [1] and [1A] values for p and q obtained by the above formulæ, and using for p' its limiting value f', the breadth of the wall may be calculated, as already shown in the article Damming, where the subject has been treated in detail by French writers.

The method of obtaining the profile of a wall or dam on the foregoing principles, as adopted by the French writers, is exceedingly complex; but W. J. M. Rankine has, in connection with the design of a large reservoir-dam in Bombay, see article on Damming, recorded a more practical way of dealing with the subject, and his process or rules may of course be applied to any retaining wall. He writes;—

"With respect to the profile of the wall, its figure is in the main to be determined by principles nearly the same with those laid down by the French engineers, and put in practice in the dams of the rivers Furens and Ban; that is to say, the intensity of the vertical pressure at the inner face of the wall should at no point exceed a certain limit when the reservoir is empty, and the intensity of the vertical pressure at the outer face of the wall should at no point exceed a certain limit when the reservoir is full.

"In the theoretical investigations of Delocre and the practical examples given by Graeff, the same limit is assigned to the intensity of the vertical pressure at both faces of the wall. But it appears to me that there are the following reasons for adopting a lower limit at the outer than at the inner face. The direction in which the pressure is exerted amongst the particles close to either face of the masonry is necessarily that of a tangent to that face; and, unless the face is vertical, the vertical pressure found by means of the ordinary formulæ is not the whole pressure, but only its vertical component; and the whole pressure exceeds the vertical pressure in a ratio which becomes the greater, the greater the batter or deviation of the face from the vertical. The outer face of the wall has a much greater batter than the inner face; therefore, in order that the masonry of the outer face may not be more severely strained when the reservoir is full than that of the inner face when the reservoir is empty, a lower limit must be taken for the intensity of the vertical pressure at the outer face than at the inner face.

"In choosing limits for the intensity of the vertical pressure at the inner and outer faces of the wall represented by the accompanying profile, Fig. 6486, I have not attempted to deduce the ratio which those quantities ought to bear to each other from the theory of the distribution of stress in a solid body; for the data on which any such theoretical determination would have to be based are too uncertain. The limits which I have chosen are as follows;—

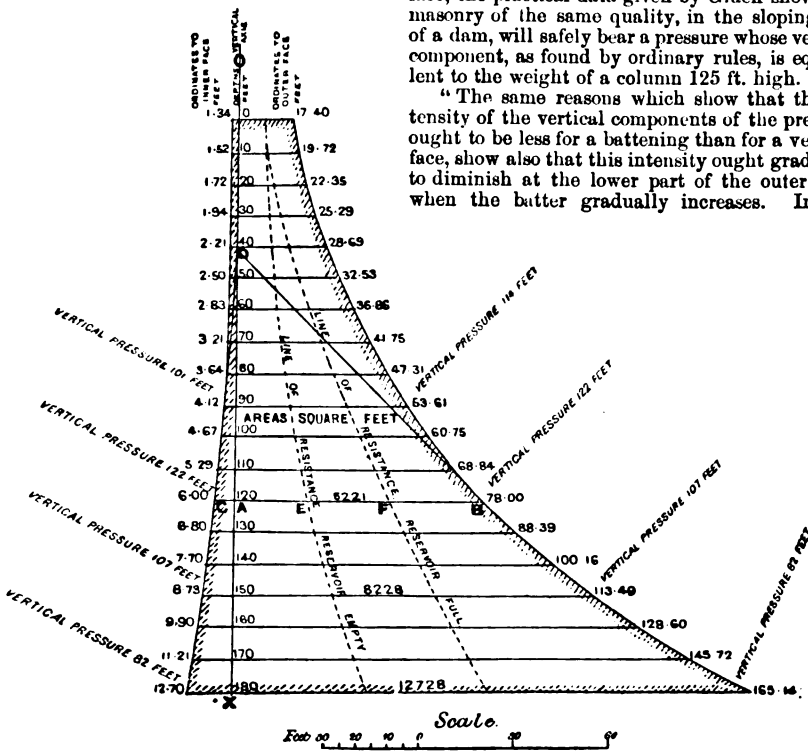
"Limits of vertical pressure at	inner face.		outer face.
In feet of masonry of 125 lbs. a cubic foot ..	160	.. ..	125
Pounds on the square foot, nearly	20,000	.. ..	15,625
Tons	8·93	.. ..	6·97
Kilogrammes on the square centimètre, nearly	9·8	.. ..	7·6
Feet of water	320	.. ..	250
Pounds on the square inch	140	.. ..	108

"In choosing these two limits I have been guided by the consideration of the following facts. As regards the inner face, where the deviation of the stress from the vertical is unimportant, it is

certain, from practical experience, that rubble masonry, laid in strong hydraulic mortar and good rock foundations, will safely bear vertical pressure equivalent to the weight of a column of masonry 160 ft. high, if not higher. As regards the outer face, the practical data given by Graeff show that masonry of the same quality, in the sloping face of a dam, will safely bear a pressure whose vertical component, as found by ordinary rules, is equivalent to the weight of a column 125 ft. high.

"The same reasons which show that the intensity of the vertical components of the pressure ought to be less for a battening than for a vertical face, show also that this intensity ought gradually to diminish at the lower part of the outer face, when the batter gradually increases. In the present state of our knowledge we should not be warranted in framing any definite theory as to the law which this diminution ought to follow; and therefore, in preparing the accompanying design I have thought it best to be guided in this, as in the previous case, by practical examples, and to consider it sufficient to make the law of diminution such that at the depth of 150 ft. below the surface the intensity of the vertical component of the pressure at the outer face becomes nearly equal to what it is at the same depth in the outer face of the dam across the Furens, namely, 107 ft. of masonry, or about 6½ kilogrammes on the square centimètre.

6486.



"I have kept in view another principle not referred to by the French authors, namely, that there ought to be no practically appreciable tension at any point of the masonry, whether at the outer face when the reservoir is empty, or at the inner face when the reservoir is full.

"Experience has shown that in structures of brickwork and masonry that are exposed to the overturning action of forces, which fluctuate in amount and direction, the tendency to give way first shows itself at that point at which the tension is greatest.

"In order that this principle may be fulfilled, the line of resistance should not deviate from the middle thickness of the wall to an extent materially exceeding one-sixth of the thickness. In other words, the lines of resistance when the reservoir is empty and full respectively, should both lie within, or but a small distance beyond, the middle third of the thickness of the wall.

"The conditions which have been observed in designing accompanying the profile, Fig. 6486, may be summed up as follows:—

"A the vertical pressure at the inner face, not to exceed 160 ft. of masonry, or 20,000 lbs. a square foot.

"B the vertical pressure at the outer face, 125 ft. of masonry, or 15,625 lbs. a square foot, at the point where it is most intense, and to diminish in going down from that point.

"C, the lines of resistance when the reservoir is full and empty respectively, to lie within, or near to, the middle third of the thickness of the wall.

"Those are the limiting conditions, and do not prescribe exactly any definite form.

"In choosing a form in order to fulfil them without any practically important excess in the expenditure of material beyond what is necessary, I have been guided by the consideration that a form whose dimensions, sectional area, and centre of gravity, under different circumstances, are found by short and simple calculations, is to be preferred to one of a more complex kind, when their merits in other respects are equal; and I have chosen logarithmic curves for both the inner and outer faces.

"The constant subtangent common to both curves, marked A D in Fig. 6486, is 80 ft.

"The thickness C B at 120 ft. below the top is 84 ft., and of this one-fourteenth, A C = 6 ft., lies inside the vertical axis O X, and thirteen-fourteenths, A B = 78 ft., outside that axis.

"The formula for the thickness t at any depth x below the top, is as follows;—

$$t = t_1 e^{\frac{x - x_1}{a}}, \qquad [1]$$

or in common logarithms,

$$\log. t = \log. t_1 + 0 \cdot 4343 \frac{x - x_1}{a},$$

in which a denotes the subtangent, 80 ft., and t_1 the given thickness, 84 ft., at the given depth, 120 ft., below the top. The thickness at the top is 18·74 ft.

"In the profile, horizontal ordinates are drawn at every 10 ft. of depth from the top down to 180 ft., and their lengths from the vertical axis O X to the inner faces respectively, are marked in feet and decimals.

"In each case those ordinates are respectively $\frac{1}{14}$ and $\frac{13}{14}$ of the thickness. Intermediate ordinates at intervals of 5 ft. can easily be calculated, if required, by taking mean proportionals between the adjacent pairs of ordinates at the intervals of 10 ft.

"The sectional area of the wall from the top down to any given depth is found by multiplying the constant subtangent a = 80 ft., by the difference, $t - t_0$, between the thickness at the top and at the given depth, that is to say,

$$\int_0^x t\,d\,x = a\,(t - t_0). \qquad [2]$$

"The vertical line through the centre of gravity of the part of the wall above a given horizontal plane stands midway between the middle of the thickness at the given horizontal plane and the middle of the thickness at the top of the wall; and thus have been found points in the curve marked line of resistance, reservoir empty.

"Supposing the reservoir filled to the level of the top of the wall, the moment of the pressure exerted horizontally by the water against each unit of length of wall from the top down to a given depth x, is found by multiplying the weight of a cubic unit of water by one-sixth of the cube of the depth; and if we take, for convenience, the weight of a cubic unit of masonry as the unit of weight, and suppose the masonry to have twice the heaviness of water, this gives us, for the moment of horizontal pressure,

$$M = \frac{x^3}{12}. \qquad [3]$$

"The moment of horizontal pressure, expressed as above stated, being divided by the area of cross-section above the given depth, gives the horizontal distance at the given depth between the lines of resistance with the reservoir empty and full respectively; that is to say,

$$\frac{M}{\int t\,d\,x} = \frac{x^3}{12\,a\,(t - t_0)}, \qquad [4]$$

and thus have been found points in the curve marked line of resistance, reservoir full.

"In the preceding formulæ the pressure of the water against the inner face of the wall is treated as if it were wholly horizontal, as in the investigations of Graeff and Delocre. In fact, however, that pressure, being normal to the inner face of the wall, has a small inclination downwards; and therefore contains a small vertical component, which adds to the stability of the wall. The neglect of that vertical component is an error on the safe side.

"To find the mean intensity of the vertical pressure on a given horizontal plane in the masonry, expressed in feet of masonry, divide the sectional area by the thickness at the given plane; that is to say,

$$\int \frac{t\,d\,x}{t} = \left(1 - \frac{t_0}{t}\right). \qquad [5]$$

"To find the greatest intensity of that vertical pressure, according to the ordinary assumption that it is an uniformly varying stress, in other words, that it increases at an uniform rate from the face farthest from the line of resistance to the face nearest to that line, the mean intensity is to be increased by a fraction of itself expressed by the ratio which the deviation of the line of resistance from the middle of the thickness bears to one-sixth of the thickness; that is to say, let p denote that greatest intensity, expressed in feet of masonry, and r the deviation of the line of resistance from the middle of the thickness; then

$$p = a\left(1 - \frac{t_0}{t}\right)\left(1 + \frac{6\,r}{t}\right).$$

When that deviation is appreciably greater than one-sixth of the thickness, the preceding rule is no longer applicable, but this case, as already explained, ought not to occur in a reservoir wall.

"The assumption on which the rule is based, of an uniform rate of variation of that component of the pressure which is normal to the pressed surface, is known to be sensibly correct in the case of beams, and is probably very near the truth in walls of uniform or nearly uniform thickness. Whether, or to what extent, it deviates from exactness in walls of varying thickness is uncertain in the present state of our experimental knowledge.

"The range of different depths to which the same profile is applicable without any waste of

material extends from the greatest depth shown on the drawing, 180 ft., up to 110 ft., or thereabouts. For depths between 110 ft. and 80 or 90 ft. or thereabouts, the waste of material is unimportant. For depths to any considerable extent less than 90 ft., the use of a part of the same profile gives a surplus of stability. For example, if the depth be 50 ft., the quantity of material is greater than that which is necessary in the ratio of 1·4 to 1, nearly. For the shallow parts, however, at the ends of a dam that is deep in the centre, I think it preferable to use the same profile as in the deep parts, notwithstanding this expenditure of material, in order that the full advantage of the abutment against the sides of the ravine may be obtained. In the case of a dam that is less deep in the centre than 110 ft., the following rule may be employed;—construct a profile similar to that suited to a depth of 110 ft., with all the thicknesses and ordinates diminished in the same proportion with the depth. The intensity of the vertical pressure at each point will be diminished in the same proportion also; but this does not imply waste of material; the whole weight of the material being required in order that there may be no appreciable tension in any part of the wall."

Although the intricate foregoing methods are imperative in structures of unusual magnitude, in order to ensure economic and safe design, yet in ordinary structures the following more simple yet sufficiently exact process may be adopted.

Returning to the principles stated at starting, we see that if we insert in equations [1] and [1A] the limiting value of $p' = f'$, and for p its value in terms of the height of the wall, we obtain an expression for h, which may be here termed the limiting height, depending on q and w_1. Using a notation as before, we have $p' = f'$, and neglecting V in equation [2], we get $p = \frac{w_1 h}{n}$; then, by equation [1],

$$h = \frac{n f'}{w_1 (1 + 6 q)}, \text{ when } q \leqq \tfrac{1}{6}; \qquad [4]$$

and by equation [1A],

$$h = \frac{3 n f' (\frac{1}{2} - q)}{2 w_1}, \text{ when } q > \tfrac{1}{6}. \qquad [4A]$$

Applying the above formulæ to the example of rectangular profiles, and taking ordinary values for f' and w_1, corresponding to ashlar and rubble, we find for the values of q, already selected in Table A, the following limiting heights;—

In the case selected the value of n is 1; but for other forms of profile the heights will increase in the ratio of n to unity; for instance, for triangular profiles, the heights will be double, and for trapezoidal profiles, $\frac{2x}{x+t}$ times those of the Table.

TABLE B.

Values of q	0	$\frac{1}{12}$	$\frac{1}{11}$	$\frac{1}{10}$	$\frac{1}{9}$	$\frac{1}{8}$	$\frac{2}{15}$	$\frac{1}{7}$	$\frac{2}{13}$	$\frac{1}{6}$	$\frac{2}{11}$	$\frac{1}{5}$	$\frac{2}{9}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
In feet, for $\frac{f'}{w_1} = \frac{20,000}{140}$, or rubble walls.																		
Limiting heights ..	160	106	103	100	96	91	89	86	83	80	75	72	68	60	40	30	15	0
In feet, for $\frac{f'}{w_1} = \frac{72,000}{170}$, or ashlar walls.																		
Limiting heights ..	424	283	274	265	254	242	235	228	220	212	198	191	177	159	106	79	40	0

An examination of the above Table shows that for walls of ordinary heights, so long as q is kept within certain limits, there will be no danger of the maximum pressure exceeding the safe limits of the resistance of the materials of the wall, and therefore, keeping in view this principle, the true proportions of a wall may be obtained from the ordinary equations for the moment of stability of structures round the assumed limiting position of the centre of resistance.

The following is the general expression for the moment of statical stability of a structure acted upon by a force tending to overturn it, and is applicable to walls;—

Let M_1 be the moment of stability relatively to the limiting position of the centre of resistance in the base; W_1 the total weight of the structure; j the angle the plane of the base makes with the horizon; $q\,x$, as before, the deviation of the centre of resistance from the middle of the base; $q'\,x$ the horizontal deviation of the vertical through the centre of gravity of the structure from the middle of the base; $(q \pm q')\,x$ will therefore be the leverage by which the weight of the structure resists overthrow. Then

$$M_1 = W_1 \cos. j\,(q \pm q')\,x; \qquad [5]$$

or, since in uniform walls $W_1 = \frac{w_1 h x}{n}$, the equation becomes

$$M_1 = \frac{w_1 h x^2}{n} (q \pm q')\,x. \qquad [6]$$

The above moment being equated with the moment of the overturning thrust, leads to ordinary quadratic equations, from which the breadth of base of walls of assured stability may be readily obtained, as employed further on. In determining the value of the fraction q to be adopted, we are

guided by the circumstances of the case. We find that in retaining walls actually constructed French engineers have on the average adopted $\frac{3}{8}$ and English engineers $\frac{1}{4}$. Also, we have seen that, to avoid the existence of any tension in the masonry, we must make $q = \frac{1}{6}$; while instances may occur where, through weakness of foundations, or from other causes, it is desirable that the pressure on the base shall be equally distributed over its surface, in which case q must be equal to o. The values of the other factors of the expression will depend on the form of the profile selected, and on the physical character of the materials used in the construction of the wall.

With respect to the *frictional* stability, we know that a wall resists sliding on a horizontal plane by an effect equal to its weight, plus the vertical component of the thrust at its back, multiplied by the coefficient of friction between its material and that of the plane on which it rests; that is, if f_0 = the coefficient of friction,

$$\text{the resistance of the wall to sliding} = (W_1 + V) f_0 ; \qquad [7]$$

and if H be the horizontal thrust = P cos. ϕ,

$$\therefore \quad H \leqq (W_1 + V) f_0 , \qquad [8]$$

from which equation may be determined the thickness of a wall necessary to fulfil the condition of frictional stability.

If we neglect V in the above equation, and substitute values already obtained for W and H, we have

$$x \geqq \frac{n H}{w_1 h f_0}. \qquad [9]$$

The coefficient of friction f_0 varies; for masonry on rock or other courses of masonry, from ·70 to ·75, and for masonry on earth foundations, from ·30 to ·35. The above formula takes no account of the cohesion of the mortar joints, which may amount to between 2000 and 3000 lbs. on the square foot. Taking cohesion into account, if c = the cohesion a unit of base, and allowing a factor of safety of 10, we have

$$x \geqq \frac{n H}{w_1 h f_0 + \frac{c}{10} n}. \qquad [10]$$

If, however, we omit cohesion from the consideration, it may be expressed that a wall will not slip on a horizontal plane, provided that f_0 is greater than $\frac{H}{W_1 + V}$; and this condition is found to be fulfilled in every wall, which otherwise satisfies the conditions of stable equilibrium.

The proposition that $\frac{H}{W_1 + V}$ be not greater than f_0 is also expressed by the condition that the tangent of the angle which the resultant R makes with the vertical shall be less than f_0; and this will be the case, for green masonry, when the angle made by the resultant is not greater than 36°; and in any given profile, the less the value of q, the less will be the angle made by the resultant.

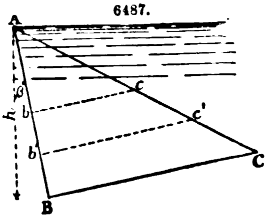
Before the design for a wall can be considered complete, the test of the above principle must be applied to it; but if there should exist any doubt as to its frictional stability, it is easy to provide greater resistance by a constructive design, in which the plane of foundations and the bed-joints of the masonry have an inclination, or slope, downwards from front to rear of the wall; or otherwise, by increasing the connection between the foundations and the courses of the masonry.

Thrust of the Material retained may for the purposes of this article be confined to fluid and earth pressure.

Fluid Pressure is exerted in all directions, equally and normal, to the planes retaining the fluid. It can arise only from the weight of the particles of the fluid over the point pressed, and is therefore proportional to the number of molecules of fluid superimposed, and consequently to the depth of the point below the surface.

If A B in Fig. 6487 represent a plane retaining a fluid, the pressure at any point is shown by a line B C, perpendicular to A B, and of a length proportional to the height multiplied by the weight of the unit of volume of the fluid; and if the triangle A B C be completed, its area represents the total pressure against the plane; and its ordinates $b\,c$, $b'\,c'$ the pressure at the various points in it.

6487.



Hence the rule for fluid pressure is;—Multiply the immersed area of the plane by the depth of its centre of gravity below the surface and by the weight of the unit of volume of the fluid. This is expressed algebraically by

$$P = w A d, \qquad [11]$$

in which P is the normal pressure; w the weight of the unit of volume of the fluid; A the wetted area of the plane pressed; d the depth of its centre of gravity measured from the surface.

For water, w is equal to 62·4, therefore P = 62·4 A d.

And if β be the inclination of the plane to the vertical, $A = \frac{h}{\cos. \beta}$; therefore the general formula for water pressure in the unit of length is

$$P = \frac{62 \cdot 4\, h\, d}{\cos. \beta}. \qquad [12]$$

Two cases only of water pressure need be considered here.

1. When the retaining plane reaches the surface of the water, as in the case of reservoir walls, Fig. 6488. Here $d = \frac{h}{2}$, and therefore

$$P = \frac{31 \cdot 2\, h^2}{\cos.\ \beta}. \qquad [13]$$

And if H be the horizontal and V the vertical component of P, then

$$H = P \cos.\ \beta = 31 \cdot 2\, h^2. \qquad [14]$$

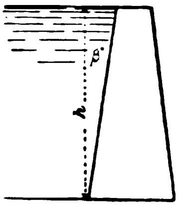
And

$$V = P \sin.\ \beta = 31 \cdot 2\, h^2 \tan.\ \beta. \qquad [15]$$

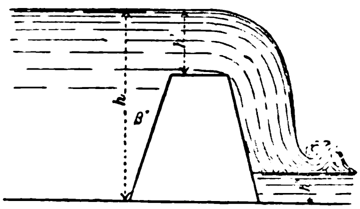
Or, simply the weight of the triangle of water vertically over the back of the wall.

2. When the plane is submerged, as in the case of weirs, Fig. 6489.

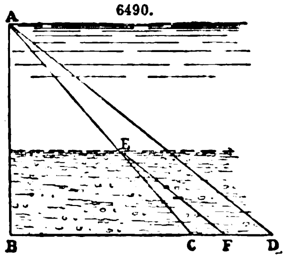
6488.



6489.



6490.



Here, $d = h' + \frac{h - h'}{2} = \frac{h + h'}{2}$; and $A = \frac{h - h'}{\cos.\ \beta}$; therefore

$$P' = 15 \cdot 6\, \frac{h^2 - h'^2}{\cos.\ \beta}. \qquad [16]$$

And

$$H' = 31 \cdot 2\, (h^2 - h'^2). \qquad [17]$$

$$V' = 31 \cdot 2\, (h^2 - h'^2) \tan.\ \beta. \qquad [18]$$

If we take a *backwater*, of the height h'', its effect, $H'' = 31 \cdot 2\, h''^2$, tends to stability.

The pressure of a fluid against the unit of surface of a plane, at any point, is $w\,h$; and the whole pressure is represented by a triangle formed by a perpendicular of this value and the height of the plane; therefore if in Fig. 6490 we let B C have the value $w\,h$ for water, and B D that for mud, the triangles A B C, A B D, will respectively represent the pressure against the plane A B in distribution and amount for these substances. For a mixed pressure of semifluid mud and water, the level of the mud being at E, draw the line E F parallel to A D, and the pressure of the mixed substances will be represented in amount and distribution by the area A B E F.

Table C.—Water Pressure against One Foot in Length of Vertical Walls.

(The Horizontal Force in lbs. = $H = 31 \cdot 2\, h^2$.)

Height of wall in feet.	Horizontal pressure in lbs.	Height of wall in feet.	Horizontal pressure in lbs.	Height of wall in feet.	Horizontal pressure in lbs.	Height of wall in feet.	Horizontal pressure in lbs.	Height of wall in feet.	Horizontal pressure in lbs.
1	31·2	31	29983·2	61	116095·2	91	258367·2	121	456799·2
2	124·8	32	31948·8	62	119932·8	92	264076·8	122	464380·3
3	280·8	33	33976·8	63	123832·8	93	269848·8	123	472024·8
4	499·2	34	36067·2	64	127795·2	94	275683·2	124	479731·2
5	780·0	35	38220·0	65	131820·0	95	281580·0	125	487500·0
6	1123·2	36	40435·2	66	135907·2	96	287539·2	126	495331·2
7	1528·8	37	42712·8	67	140056·8	97	293560·8	127	503224·8
8	1996·8	38	45052·8	68	144268·8	98	299644·8	128	511180·8
9	2527·2	39	47455·2	69	148543·2	99	305791·2	129	519199·2
10	3120·0	41	52447·2	71	157279·2	101	318271·8	131	535423·2
11	3775·2	42	55036·8	72	161740·8	102	324604·8	132	543628·8
12	4492·8	43	57688·8	73	166264·8	103	331000·8	133	551896·8
13	5272·8	44	60403·2	74	170851·2	104	337459·2	134	560227·2
14	6115·2	45	63180·0	75	175500·0	105	343980·0	135	568620·0
15	7020·0	46	66019·2	76	180211·2	106	350563·2	136	577075·2
16	7987·2	47	68920·8	77	184984·8	107	357208·8	137	585592·8
17	9016·8	48	71884·8	78	189820·8	108	363916·8	138	594272·8
18	10108·8	49	74911·2	79	194719·2	109	370687·2	139	602815·2
19	11263·2	51	81151·2	81	204703·2	111	384415·2	142	629116·8
21	13759·2	52	84364·8	82	209788·8	112	391372·8	144	646963·2
22	15100·8	53	87640·8	83	214936·8	113	398392·8	146	665059·2
23	16504·8	54	90979·2	84	220147·2	114	405475·2	148	683404·8
24	17971·2	55	94380·0	85	225420·0	115	412620·0	149	692671·2
25	19500·0	56	97843·2	86	230755·2	116	419827·2	150	702000·0
26	21091·2	57	101368·8	87	236152·8	117	427096·8		
27	22744·8	58	104956·8	88	241612·8	118	434428·8		
28	24460·8	59	108607·2	89	247135·2	119	441823·2		
29	26239·2								

Rule and Example.—To find the horizontal pressure of water against 1 ft. in length of a *vertical* wall 10 ft. high? By Table, H = 3120 lbs. If the wall *slopes* β° at back, for the vertical element V, multiply the tabular number by the tangent of angle of slope β, and for the normal pressure N, multiply the tabular number by the secant of the angle of slope β. *Example.*—If back of above wall sloped forward 10° ∴ V = 3120 × tan. 10° = 3120 × ·176 = 549·1 lbs., and N = 1320 × sec. 10° = 3120 × 1·015 = 3166·8 lbs. To find horizontal pressure against a wall 10·6 ft. high, take that in the Table for 106 ft., and point off two decimal places, thus, pressure for 106 ft. = 350563·2 lbs., pressure for 10·6 ft. = 3505·632 lbs., for 1·06 ft. = 35·05632 lbs.

The pressure of sea-water, or mud in a semifluid state, may be obtained from equations [13] to [18], or from the Table, p. 2735, by multiplying the result for water by the specific gravity of the heavier material. The specific gravity of sea-water is about 1·026, and that of mud varies with its consistency and constitution.

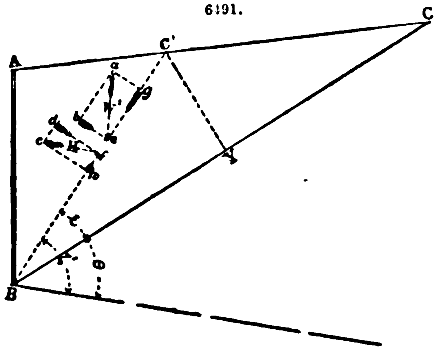
The Pressure of Earth.—The accurate determination of the pressure of earth against a fixed plane is as yet involved in obscurity; but the following theory based on the investigations of Prony and Coulomb, is that which accords most closely with experience, and offers the most philosophical treatment of the subject. It agrees nearly in results with the more complicated treatment of the question by Rankine; the equations for the special cases of vertical walls being identical.

This theory is based on the principle of the inclined plane, and received laws of friction; while the assumptions made all tend to exaggerate the pressure to be provided for, and thus introduce an element of safety. The results of the deductions regarding the thickness of walls to resist the pressure found by our formula also fairly agree with the results of experience.

It is assumed that the earth is loose, and of uniform density; that the effect of cohesion is neglected; that there is no friction between the earth and the resisting plane. It is observed that where loose earth is filled in behind a fixed plane, the resistance of the plane retains the mass, but that when the plane is removed the particles of the earth slip or roll amongst each other, till the vertical through the centre of gravity of each particle makes with the perpendicular to a certain plane in the mass, an angle equal to the angle of repose, or limiting angle of friction. This angle is that which the plane called the natural slope makes with the horizontal, and its tangent is equal to the coefficient of friction.

Let A B, Fig. 6491, be a plane retaining a bank of earth. When it is removed a mass A B C will slip down. B C is the natural slope, and θ the angle of repose.

6491.



If we conceive the whole mass solidified there would be no pressure, as the component of gravity down the plane is in equilibrium with the friction between the mass and the plane B C. We must therefore consider the pressure to be produced by some smaller mass, such as A B C' slipping down some other plane, making a greater angle, $\theta + E = i$ with the horizontal.

The horizontal pressure of any mass resting on a plane making an angle i, is obtained by resolving the forces produced by the weight of the mass A B C' = W, and the horizontal resistance = H, in directions parallel and perpendicular to the plane B C'.

Resolving W and H in directions along, and perpendicular to, the plane, and observing that they act in opposite directions, we have $\overline{g\,e}$ representing the force down the plane = W sin. i, and $\overline{h\,f}$ representing the force up the plane = H cos. i.

The motion *down* the plane is opposed by the force (W cos. i + H sin. i) tan. θ, which is the amount of the friction developed by the normal components of H and W.

Whence, as there is supposed equilibrium, W sin. i = H cos. i + (W cos. i + H sin. i) tan. θ, multiplying by cos. θ and arranging, H (cos. i cos. θ + sin. i sin. θ) = W (sin. i cos. θ − cos. i sin. θ), therefore as $(i - \theta) = e$ we obtain

$$H = W \tan. e, \qquad [19]$$

or if w be the weight of the unit of mass (1 cub. ft.) of the earth, and A the area of the triangle A B C', the horizontal thrust is

$$H = w\,A \tan. e. \qquad [20]$$

It can be shown by the principles of Maxima and Minima, that A tan. e will be a maximum, when the plane B C' has such a position that the area of the triangle A B C' formed between it and the plan A B, and that of a triangle B C' Y, formed by it and a perpendicular C' Y, let fall from C' on the plane of natural slope B C, are equal; or in symbols, when $A = \dfrac{\overline{B\,Y} \times \overline{C'\,Y}}{2}$ and because $\overline{B\,Y} = \dfrac{\overline{C'\,Y}}{\tan. e}$, therefore $A = \dfrac{\overline{C'\,Y}^2}{2 \tan. e}$. Substituting this value for A in equation [20] we have

$$H = \frac{w\,\overline{C\,Y}^2}{2}, \qquad [21]$$

another general expression for the horizontal thrust.

The following geometrical construction, by Neville, see Fig. 6492, determines the position of the plane B C', when A tan. e is a maximum. Let A B be the face of a bank, D C its surface,

B C the plane of natural slope. Draw B E parallel to A C, and O P at right angles to B C. Cutting A B produced if necessary. On O P describe a semicircle O H P, and from P as centre and with P H as radius describe an arc cutting O P in I, and through I draw B C′ which is the plane of maximum pressure as required, making the triangles A B C′ and B C′ Y, Fig. 6491, equal.

The value of tan. e is

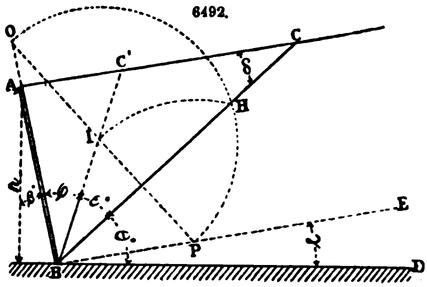
$$\tan. e = \sqrt{\tan.^2(\theta \mp \gamma) + \tan.(\phi + e)\tan.(\phi \mp \gamma)} - \tan.(\theta \mp \gamma), \qquad [22]$$

or, in a form more suitable for logarithms,

$$\tan. e = \tan.(\theta \mp \gamma)\left(1 - \sqrt{\frac{\sin.(\phi + e + \delta)}{\sin.\delta\cos.(\phi + e)}}\right). \qquad [22\text{A}]$$

The sign − or + being used according as the surface A C is over or under the horizontal.

6492.



The value of $\overline{C\,Y}$ may readily be obtained by the construction, or from its trigonometric equivalent,

$$\overline{C\,Y} = \overline{A\,B}\frac{\sin.(\phi + e + \delta)\sin.e}{\sin.(2\phi + e + \delta)}. \qquad [23]$$

The value of A is

$$\frac{\overline{A\,B}^2\sin.\phi\sin.(\phi + e + \delta)}{2\sin.(2\phi + e + \delta)}, \qquad [24]$$

and substituting these values of A and $\overline{C\,Y}$, we get a general equation for the pressure of a bank of loose earth of any face batter or surface slope, in terms of e.

$$H = w\,A\tan.e = \frac{w\,\overline{A\,B}^2}{2}\cdot\frac{\sin.\phi\sin.(\phi+e+\delta)}{\sin.(2\phi + e + \delta)}\tan.e = \frac{w\,\overline{C\,Y}^2}{2} = \frac{w\,\overline{A\,B}^2}{2}\,\frac{\sin.^2(\phi+e+\delta).\sin.^2 e}{\sin.^2(2\phi + e + \delta)} \quad [25]$$

The two following cases are of most frequent occurrence;—

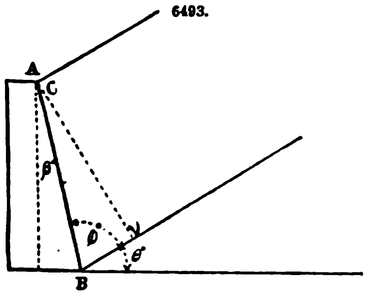
I. When the surface of the bank *slopes up at the angle of repose*, that is to say, when the wall is indefinitely surcharged, Fig. 6493. Here $\overline{C\,Y} = \overline{A\,B}\sin.\phi$, therefore

$$H = w\frac{\overline{A\,B}^2}{2}\sin.^2\phi. \qquad [26]$$

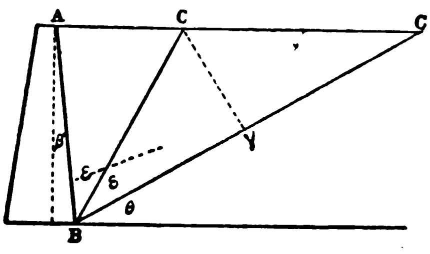
When the back is vertical, $\overline{A\,B} = h$, therefore

$$H = \frac{w\,h^2\cos.^2}{2}\theta. \qquad [27]$$

6493.



6494.



II. When the surface of the bank is *horizontal*, Fig. 6494, $\overline{C\,Y} = \overline{A\,B}\frac{\cos.\beta\sin.e}{\sin.(\theta + e)}$, therefore

$$H = \frac{w\,\overline{A\,B}^2}{2}\cdot\frac{\cos.^2\beta\sin.^2 e}{\sin.^2(\theta + e)}. \qquad [28]$$

When the back is vertical, $\overline{A\,B} = h$, and $\overline{C\,Y} = \overline{A\,C} = h\tan.e$, and $e = \phi$, therefore

$$H = \frac{w\,h^2}{2}.\tan.^2\frac{90 - \theta}{2}. \qquad [29]$$

The following Table of coefficients of $w\,h^2$ will shorten the calculation of the horizontal thrust of earthen banks against walls, in the two cases given above, for some of the usual batters, and for natural slopes of from 27° to 48°. It also shows at a glance how the pressure varies with the batter and angle of repose, and also with the slope of the surface.

Rules and Examples.—To find the horizontal pressure, acting at one-third the height, against 1 ft. in length of a retaining wall. Multiply the weight of a cubic foot of the earth by the square of the height of the wall and by the tabular coefficient for the proper inclination of the surface, angle of repose of the earth, and batter of back of wall.

Example 1.—Horizontal pressure of a bank of earth with *horizontal surface* against a wall 10 ft. high; weight of cubic foot earth = 100 lbs.; angle of repose 40°.

TABLE E.—COEFFICIENTS FOR EARTH PRESSURE AGAINST ONE FOOT IN LENGTH OF SLOPING AND VERTICAL BACKED WALLS, OBTAINED FROM FORMULÆ 28 AND 29.

Angle (β°) of Repose.	1. Surface of Bank Horizontal.							2. Surface of Bank Sloping up at Angle of Repose.						
	Slope of Back of Wall.							Slope of Back of Wall.						
	Overhanging forwards.			Plumb.	Reclining.			Overhanging forwards.			Plumb.	Reclining.		
	14° or 1 in 4.	10° or 1 in 6.	5° or 1 in 12.	0°	5° or 1 in 12.	10° or 1 in 6.	14° or 1 in 4.	14° or 1 in 4.	10° or 1 in 6.	5° or 1 in 12.	0°	5° or 1 in 12.	10° or 1 in 6.	14° or 1 in 4.
27	·289	·252	·218	·188	·166	·141	·125	·504	·471	·433	·397	·362	·329	·302
28	·280	·244	·212	·180	·157	·133	·120	·499	·466	·427	·389	·355	·320	·293
29	·270	·236	·204	·173	·150	·129	·114	·495	·461	·421	·383	·341	·311	·284
30	·261	·228	·194	·167	·145	·124	·108	·490	·455	·414	·375	·339	·303	·275
31	·252	·220	·190	·160	·138	·117	·103	·485	·449	·407	·367	·330	·294	·265
32	·243	·213	·183	·153	·132	·111	·097	·480	·443	·400	·359	·321	·285	·256
33	·230	·204	·176	·147	·126	·106	·092	·474	·437	·393	·351	·313	·276	·247
34	·226	·197	·169	·141	·122	·101	·087	·468	·430	·386	·343	·304	·267	·240
35	·218	·190	·161	·135	·116	·095	·082	·462	·423	·378	·335	·296	·253	·228
36	·210	·183	·156	·130	·110	·090	·078	·456	·416	·370	·327	·287	·249	·219
37	·203	·174	·149	·124	·105	·087	·073	·449	·409	·362	·319	·278	·240	·210
38	·196	·170	·144	·119	·101	·083	·069	·438	·402	·355	·310	·270	·231	·201
39	·189	·164	·139	·114	·095	·077	·065	·436	·394	·341	·302	·261	·222	·192
40	·182	·157	·132	·108	·091	·074	·061	·428	·387	·339	·293	·252	·213	·183
41	·176	·151	·127	·104	·086	·069	·058	·421	·379	·333	·284	·243	·205	·174
42	·169	·146	·123	·099	·082	·066	·054	·413	·371	·321	·276	·234	·195	·166
43	·163	·139	·117	·094	·078	·062	·051	·405	·363	·313	·267	·226	·187	·157
44	·156	·135	·110	·090	·073	·057	·047	·398	·354	·304	·259	·217	·178	·152
45	·150	·129	·107	·085	·069	·054	·044	·390	·346	·296	·250	·208	·170	·141
46	·145	·124	·103	·081	·066	·051	·041	·381	·337	·287	·241	·200	·162	·130
48	·134	·113	·092	·073	·059	·045	·036	·364	·320	·270	·224	·183	·145	·117

a. When back is *vertical*, $P = w\,h^2 \times$ coefficient $= 100 \times \cdot 108 = 1080$ lbs.

b. When back *overhangs* 10°, that is to say, batters out towards the face 1 in 6; $P = w\,h^2 \times$ coefficient $= 10{,}000 \times \cdot 157 = 1570$ lbs.

c. When back *reclines* 10°, that is to say, batters in towards the earth 1 in 6; $P = w\,h^2 \times$ coefficient $= 10{,}000 \times \cdot 074 = 740$.

Example 2.—Horizontal pressure of a bank of earth, *surface sloping up* at angle of repose. Bank of wall *overhanging* 10°.

$w = 100$, $h = 10$, $\theta^\circ = 40^\circ$, $\beta^\circ = 10^\circ$ $\therefore$ $P = w\,h^2 \times$ coefficient $= 100 \times 10^2 \times \cdot 387 = 2870$ lbs.

The Moment of the Pressure of Water or Earth tending to overturn walls is the horizontal component of the thrust multiplied by the vertical height of the point of application of its resultant over the centre of resistance of the base, and this is diminished by the vertical component multiplied by the horizontal distance of the same point from the limiting position of the centre of resistance. The point of application of the resultant of the thrust against a plane is called the *centre of pressure*, and is situated where the normal through the centre of gravity of the ideal figure, representing the pressure against the plane, cuts the plane.

Let h be the total depth of the base below the surface; h_1 the depth of the top of a submerged plane, such as a weir; the vertical height of the centre of pressure over the base is,

For planes reaching the surface,

$$z = \frac{h}{3}; \qquad [30]$$

For planes submerged,

$$z = h - \frac{2}{3}\,\frac{h^3 - h_1{}^3}{h^2 - h_1{}^2}. \qquad [31]$$

The horizontal distance of the centre of pressure from the centre of resistance of the base is $y = x\,(\tfrac{1}{2} + q) - \frac{r_1\,h}{3}$, where $r_1\,h$ is the batter of the back of the wall, and x and q as before.

If then, P be the total thrust against the wall at back, and ϕ the angle which its direction makes with the horizontal, the expression for the resulting moment is

$$M = P\,(z \cos.\,\phi - y \sin.\,\phi); \qquad [32]$$

or, if H and V be the horizontal and vertical components of P,

$$M = H\,z - V\,y. \qquad [33]$$

The Shock of a Current is an overturning thrust that may sometimes, as in weirs, have to be taken into account, in addition to the hydrostatic pressure. The pressure of a current against a plane at right angles to its direction is proportional to the area of the plane, and the height due to the velocity of the stream.

Let w be the density of the fluid; a, the area of the plane (for the unit of length a becomes h); q the force of gravity in feet, seconds; v the velocity of the current in feet, seconds. Then the theoretic force is $\frac{w\,a\,v^2}{29} = \frac{w\,a\,v^2}{64 \cdot 4}$. For water this becomes for a unit of length,

$$\cdot 969\, h\, v^2. \qquad [34]$$

According to Duchemin's experiments, the actual force against thin planes, which may be taken as weirs, in pounds a square foot, is

$$F = 1 \cdot 8\, h\, v^2. \qquad [35]$$

As it acts at the centre of gravity of the plane, therefore, $z = \frac{h}{2}$. The *moment* of this force, which must be added to the moment of the hydrostatic pressure, is therefore

$$M_0 = \frac{F\,h}{2} = 1 \cdot 9\, h^2\, v^2. \qquad [36]$$

Examples of the force of a current against 1 ft. in length of vertical planes, calculated by the above formula—[35]—are as follows;—

TABLE F.

Height of Wall.	Velocities of Current in feet a second.							
	1	2	3	4	5	6	7	8
feet.	Force (F) in lbs. to the Unit of Surface.							
1	1·8	7·2	10·8	28·8	45·0	64·8	88·2	115·2
10	18	72	108	288	450	648	882	1152
20	36	144	216	576	900	1296	1764	2304
30	54	216	324	864	1350	1944	2646	3456
40	72	288	432	1152	1800	2592	3528	4608
50	90	360	540	1440	2250	3140	4410	5760

The Thickness of Wall is found for any point by equating the moment of stability of the wall over the point, as given in equations [5] and [6], with the moment of the overturning thrust, as obtained from equations [11] to [33]; that is to say, we make $M' = M$. Thus, for uniform walls under ordinary earth or water pressure, we have

$$W_1 \cos. j\,(q \pm q')\,x = H\,z - V\,y. \qquad [37]$$

This expression is simplified by confining the investigation to walls on horizontal bases, and neglecting the vertical component of the thrust V, which introduces an element of safety; also assuming that the profile of the wall remains uniform, in which case $W_1 = \frac{w_1\,h\,x}{n}$, the equation between the statical resistance and the moment of the horizontal thrust becomes

$$\frac{w_1\,h\,x^2}{n}\,(q \pm q') = H\,z, \qquad [38]$$

whence, for retaining walls and dams, in which $z = \frac{h}{3}$, we have the general equation for the breadth of base as follows;—

$$x = \sqrt{\frac{n\,H}{3\,w_1\,(q \pm q')}}. \qquad [39]$$

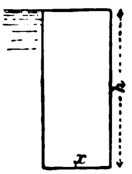
For other descriptions of thrust and values of z, the same principle of equating the moments is to be adopted, and will lead to equations of a similar character; but the investigations cannot be here carried out for want of space.

The following are some of the applications of formula [39], which may be useful in practice;—

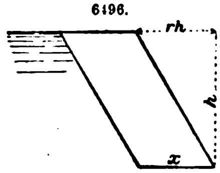
1. Vertical rectangular sections, Fig. 6495, $n = 1$; $q' = 0$;

$$\therefore\ x = \sqrt{\frac{H}{3\,w_1\,q}}. \qquad [40]$$

6495.



6496.



2. Reclining rhomboidal sections of uniform breadth, Fig. 6496. Let $r\,h$ be the face batter, $n = 1$, $q' = \frac{r\,h}{2\,x}$;

$$\therefore\ x = \sqrt{\frac{H}{3\,w_1\,q} + \left(\frac{r\,h}{4\,q}\right)^2} - \frac{r\,h}{4\,q}. \qquad [40\text{A}]$$

3. Reclining curved sections of uniform breadth, Fig. 6497. Approximately $n = 1$, and $q' = \frac{2\,r\,h}{3\,x}$;

$$\therefore\ x = \sqrt{\frac{H}{3\,w_1\,q} + \left(\frac{r\,h}{3\,q}\right)^2} - \frac{r\,h}{3\,q}. \qquad [40\text{B}]$$

In these two last cases, when the centre of gravity of the section is over the inner angle of the base, $q' = \frac{1}{2}$;

$$\therefore \quad x = \sqrt{\frac{\mathrm{H}}{3\,w_1\,(q + \frac{1}{2})}}. \qquad [40\text{C}]$$

4. Trapezoidal sections, with a determinate *face* batter, Fig. 6498. Let t be the top breadth,

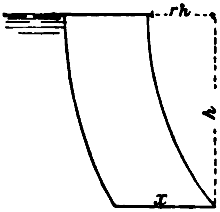
$$n = \frac{x + t}{2\,x},\ q' = \left(\frac{r\,h}{3} + \frac{t - x}{6}\right)\frac{x + 2\,t}{x\,(x + t)};$$

$$\therefore \quad x = \sqrt{\frac{2\,\mathrm{H}}{3\,w_1\,(q - \frac{1}{6})} - \frac{2\,r\,h\,t + t^2}{3\,(q - \frac{1}{6})} + \left(\frac{r\,h}{6\,q - 1} + \frac{t}{2}\right)^2} - \left(\frac{r\,h}{6\,q - 1} + \frac{t}{2}\right). \qquad [40\text{D}]$$

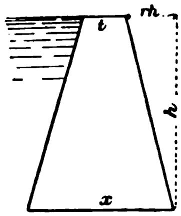
When a wall of this section is plumb *faced*, $r\,h = 0$;

$$\therefore \quad x = \sqrt{\frac{2\,\mathrm{H} - w_1\,t^2}{2\,w_1\,(q - \frac{1}{6})} + \left(\frac{t}{2}\right)^2} - \frac{t}{2}. \qquad [40\text{E}]$$

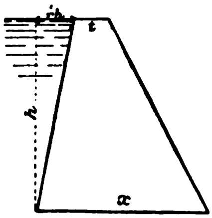
6497.



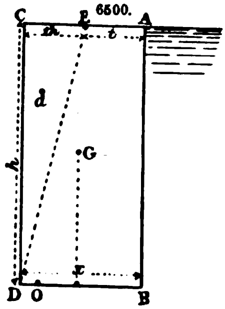
6498.



6499.



6500.



5. Trapezoidal sections, with a determinate *back* batter, Fig. 6499. Let $r'\,h$ be the back batter,

$$n = \frac{x + t}{2\,x},\ q' \doteq \left(\frac{x - t}{6} - \frac{r'\,h}{3}\right)\frac{x + 2\,t}{x\,(x + t)};$$

$$\therefore \quad x = \sqrt{\frac{2\,\mathrm{H}}{3\,w_1\,(q + \frac{1}{6})} + \frac{2\,r'\,h + t^2}{3\,(q + \frac{1}{6})} + \left(\frac{t}{2} - \frac{r\,h}{6\,q + 1}\right)^2} - \left(\frac{t}{2} - \frac{r\,h}{6\,q + 1}\right). \qquad [40\text{F}]$$

When a wall of this section is plumb *backed*, $r'\,h = 0$;

$$\therefore \quad x = \sqrt{\frac{2\,\mathrm{H} + w_1\,t^2}{3\,w_1\,(q + \frac{1}{6})} + \frac{t^2}{2}} - \frac{t}{2}. \qquad [40\text{G}]$$

Transformation of Profiles.—Rankine points out that a portion of the outer face of a rectangular wall may be removed without in any way influencing the statical stability of the wall, provided that the vertical let fall from the centre of gravity of the part taken away does not pass behind the centre of resistance of the wall base. This produces a trapezoidal section, and therefore economy of design.

In Fig. 6500, suppose the triangular portion C D E of a rectangular profile A B C D to be removed; then, if its centre of gravity g be vertically over O, the centre of resistance of the base, the weight of the mass C D E can have no influence on the stability of the wall, and we have a trapezoidal section A B D E of equal moment of stability, as regards the point O, with that of the rectangular section A B C D, and also of the same breadth of base.

Let $\overline{\mathrm{E\,A}} = t$; $\overline{\mathrm{C\,E}} = r\,h$; $\overline{\mathrm{D\,B}} = x$; then

$$t = x - 3\,x\,(\tfrac{1}{2} - q) = (3\,q - \tfrac{1}{2})\,x, \qquad [41]$$

$$r\,h = 3\,x\,(\tfrac{1}{2} - q) = x - t. \qquad [42]$$

Therefore for

$$q = \frac{1}{6},\ \frac{2}{11},\ \frac{1}{5},\ \frac{2}{9},\ \frac{1}{4},\ \frac{1}{3},\ \frac{3}{8},\ \frac{7}{16},\ \frac{1}{2}.$$

$$t = 0,\ \frac{x}{22},\ \frac{x}{10},\ \frac{x}{6},\ \frac{x}{4},\ \frac{x}{2},\ \frac{5}{8}x,\ \frac{21}{16}x,\ x.$$

$$r\,h = x,\ \frac{21}{22}x,\ \frac{9}{10}x,\ \frac{5}{6}x,\ \frac{3}{4}x,\ \frac{x}{2},\ \frac{3}{8}x,\ \frac{5}{16}x,\ 0.$$

When q is less than $\frac{1}{6}$ the rule is not applicable.

Vauban's rule for the transformation of profiles is, that a rectangular profile may be converted into one of equal stability, but with a face batter, by making the face line of the rectangle revolve on a horizontal axis at $\frac{1}{6}$ the height of the wall. This rule holds good with an error less than $\frac{1}{140}$ part, while the batter is not greater than $\frac{1}{6}$ the height and $\frac{1}{70}$ part when the batter is greater.

The Table for the thickness of retaining walls of various batters, given in Molesworth's Pocket-Book of Engineering Formulæ, is based on the above rule, combined with equations [29] and [40] of this article.

Calculations should be based on correct data, obtained in each individual case by experiment, on the materials to be retained and used in the construction; but in case of preliminary calculations or provisional design the following Tables of data, taken from various authorities, may prove useful.

TABLE G.

Materials of Construction.	Specific Gravity.	Weight of a Cubic Foot.
		lbs.
Basalts and traps	3 to 2·4	187 to 155
Bricks, red	2·16	135
„ common	1·76	110
„ stock (London)	1·84	115
Brickwork, in cement	1·92	120
„ in new mortar	1·87	117
„ old	1·52	95
„ ordinary	1·61	100
Cement, new	1·61	100
Flint masonry	2·34	148
Granites	3·05 to 2·25	190 to 141
Granite masonry	2·75	172
Limestones	2·54 to 1·86	159 to 116
Mortars, new	1·9	119
„ old	1·42	89
Sandstones	2·67 to 1·38	168 to 88
Slates	2·9 to 2·5	180 to 157

Weight of a cubic foot of ashlar masonry is about $\frac{7}{8}$ths weight of a cubic foot of the stone + $\frac{1}{8}$th weight of a cubic foot of the mortar. Weight of a cubic foot of rubble masonry is from $\frac{3}{4}$ths to $\frac{2}{3}$rds weight of a cubic foot of the stone + $\frac{1}{4}$th to $\frac{1}{3}$rd weight of a cubic foot of mortar.

TABLE H.

Materials retained by Walls.	Specific Gravity.	Weight of a Cubic Foot.	Angles of Repose.
		lbs.	°
Clay, dry	1·95	120	30 to 40
„ wet	2·17	135	15 „ 20
Earth, common dry	1·64	102	46
„ dense compact	..	..	55
Earthy clay and sand	1·5 to 1·7	97 to 106	54
Gravel	1·54 „ 1·95	96 „ 120	37
Mould, garden	1·4	70 „ 90	35 to 45
Sand, dry fine	1·37 to 1·55	84 „ 97	34 „ 40
„ damp	1·9	118	..
Shingle, loose	2·2	139	39
Water, fresh	1·0	62·4	0
„ salt	1·027	64·18	0

TABLE I.—WORKING LOADS, OR SAFE UNITS OF PRESSURE ADOPTED IN EXISTING STRUCTURES.

	Tons on the Square Foot.	Pounds on the Square Inch.
Soft rock foundations	9	140
Concrete „	3	46
Earth „	$1\frac{1}{4}$	20
Ashlar masonry, limestone, Britannia Bridge	16	249
„ „ granite, Saltash Bridge	10	156
„ backed with rubble, Peniston Viaduct	6	93
Rubble masonry, sandstone in Aberthaw lime, Pont-y-Pridd	$20\frac{3}{4}$	321
„ limestone in chalk lime, Barentine Viaduct	$3\frac{1}{2}$	54
„ in hydraulic lime, Almanza Dam	12·8	199
„ „ Ban „	7·3	115
„ „ Furens „	6	93
„ Toolsee „	8·9 to 6·9	140 to 108
Brickwork, London pavior's in cement, Charing Cross Bridge	12	187
„ Staffordshire blue brick in cement, Clifton Suspension Bridge	10	156
„ red Birmingham in lias lime, Railway Viaduct	7	109
Cement mortar	20 to 32	300 to 500
Lime „	$2\frac{1}{2}$ „ $5\frac{1}{4}$	40 „ 80

Practical Design and Construction.—The foundations of retaining walls should be particularly secure, and especially so in walls with battering backs; because, as our theory points out, the vertical component of the pressure of the material retained adds to the pressure of the structure on its base.

In order to distribute the weight over a greater area, and also to bring the centre of the base more nearly to coincide with the centre of resistance, the masonry in the foundations is usually arranged as steps; the width increasing by a series of offsets. In all cases where the ground is soft or treacherous, care must be taken that the greatest intensity of the pressure shall not exceed the power of the strata to resist compression or displacement. In such situations the maximum of statical stability will be gained by using light materials, such as brickwork; or by adopting a form of hollow walls, as used by Rennie at Sheerness, and by making q, in the formula, as small as possible. The centre of resistance of a wall under water-pressure may be made to coincide with the centre of figure of the base by making the profile that of an isosceles triangle whose base angles are $35\frac{1}{4}^{\circ}$, the breadth of base of such wall will be 1·414 times the height of wall. Unless the coefficient of friction exceeds 0·25, the weight of a cube foot of the masonry of a dam of this section must exceed 145 lbs., otherwise the wall may slide forward.

When the frictional stability is doubtful, the foundation bed must be excavated so as to incline from front to rear of the wall, thus placing the structure as it were on an inclined plane, up which it must be forced by the pressure from behind. At the same time every possible expedient should be adopted to drain and thus render solid the strata both in front and rear of the masonry; while, when the ground is obviously insecure, piling must be resorted to, the piles being driven with a rake or batter, so as to be perpendicular to the plane of the bed of the foundations; or, redan-shaped excavations may be formed in the bed so that the masonry may key itself therein.

The wall on the Birmingham, Bristol, and Thames Junction Railway, 150 ft. of which moved bodily forward 10 ft., the wall still standing, is an instance of failure from insufficient frictional stability; Vignoles considered the exciting cause to be an unexpected accumulation of water at the rear of the wall. Huntsbank wall on the river Irwell, which was forced into the water, is another instance. This wall was built of ashlar, and was 20 ft. high, $3\frac{1}{2}$ ft. thick at top, and 5 ft. thick at bottom, with counterforts.

Form of Profile.—Walls are built of numerous forms of profile or cross section, varying from the rectangular to the triangular. A triangle is that figure which is theoretically the most economical; and the nearer that practical conditions will allow of its being conformed to the better.

All other things being equal, the greater the face batter, the greater will be the stability of the wall; but considerations connected with the functions of the wall limit the full application of this condition, and walls are usually constructed with only a moderate batter on the face, the diminution towards the top being obtained by a back batter worked out in a series of offsets or steps in the masonry.

Weirs generally batter very little on the face, in order that the water may spill clear of the masonry, out of the joints of which it would be likely to wash the mortar. A very large face batter promotes the action of frost on the pointing, and also facilitates the growth of vegetation in the joints, which is often highly injurious. The filling at the back rests on the steps forming the back batter, thus adding to the stability of the wall; and if dry rubble be hand-packed over these offsets, the stability will be very nearly as great as if the wall were built up plumb at back of solid masonry. In brick walls these offsets are usually reckoned in half bricks.

A common practical rule for the form of wing wall of bridges at the back is to carry up the base thickness for one-third the height, and thence diminish off to the top breadth by offsets.

Curved forms of profile are often adopted in brick walls, and especially in walls for dock and harbour work, where practically the curved batter suits the shape of vessels lying alongside the wharfs, and it is considered to have a superiority in throwing back the crests of waves striking sea-walls. The effect of a curved profile, as in Fig. 6509, is to increase the statical stability of the wall by throwing back its centre of gravity, and this increase over a rhomboidal section with rectilineal batters is in the ratio of 4 to 3. A curved wall may possibly offer a slightly greater resistance to bulging in its lower parts; but, as Arthur Jacob has pointed out, it cannot act as an arch, having only *one* abutment; and it has little in it to counterbalance the disadvantage of being a much more expensive form to construct. The radius usually adopted for the curved face of a wall is three times the height of the wall. It will be found that if with this radius the centre of the curve be taken in the horizontal through the top of the wall, the batter of the chord of the arc will be very nearly one-sixth of the height. This good practical relation is probably the origin of the rule for the length of the radius.

The Masonry of Walls.—Where the foundations are reliable, the weightier the walls can be made the more stable they will be, so that for the masoury of well-founded walls, heavy stones, such as granite, basalt, and limestone will be preferable to brick, or the lighter stones. The action of destructive agencies, and the intensity of the pressure being greater towards the face of the wall, has led to the use of a superior class of masonry in this part, the ashlar, or block-in-course facing being backed with rubble, brick, or concrete, for the sake of economy; but such combinations must be introduced with the greatest caution and skill, so that no unequal settlement, and consequent separation of the facing and backing, shall be likely to occur. Long headers should be plentifully introduced, and the work should not be run up too rapidly. The superior class of masonry used in the facing should reach back into the wall to a sufficient distance, so that the intensity of the pressure on the masonry at the junction of the facing and backing may be well within the safe limit of resistance of the weaker materials.

The use of concrete for the interior of walls under water-pressure is common because of the greater thickness of such walls, and because of the greater density and impermeability of well-made concrete. Care should be taken in settling the proportions of the materials of the concrete that the lime shall fully occupy all the interstices of the shingle, sand, or metal used, and that it shall

possess superior hydraulic properties if it is not actually a cement. The materials for the concrete should not be too large, and it is believed that sand or a very fine gravel would produce a more dense and reliable concrete than larger stuff. It is, however, very doubtful whether good uncoursed rubble masonry, in which the stones are properly selected and fitted and carefully laid flush in mortar by skilled workmen, would not be superior to concrete on the grounds of both solidity and compactness, and such masonry has been adopted in the largest masonry dams yet constructed, and with the greatest success. The masonry in the backs of weirs and dams for a few feet above and below the range of the water-line should be of superior character, and the same may be said of the faces of wharf walls, as such parts may be exposed to the shock of waves or floating bodies.

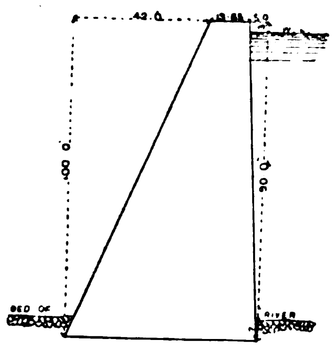
The copings of all retaining walls should be of good heavy and large stones laid as headers, which may for wharf walls be cramped, keyed, or dowelled together. In weirs, beside the above precaution, the joints should be very close, and the crest stones should be set with a counter-slope to the direction of the current, the inner edge being rounded off to a semicircular form, which will facilitate the discharge of the water over the crest, and render the stones less liable to displacement. In brick walling the use of English bond is recommended, and half-bricks may be used as every alternate header, so as to increase the bond in the interior of the wall. In brick walls the pointing should be very carefully attended to, so as to resist the action of frost, and especially so in walls with a batter on the face.

Dams and Weirs.—These structures require special care in founding equally with other retaining walls. Water must be effectually excluded from their bases, so as to prevent waste of water, and preclude all danger of their being blown up and forced forward. The foundations of dams are sometimes connected with the rock on which they rest by large stones let, as dowels, into the rock and projecting up into the wall, or by redan-shaped hollows, excavated in the rock into which the masonry of the wall is, as it were, rooted and keyed. Through courses of masonry in dams are to be avoided as forming planes along which leaks are liable to establish themselves; and for this reason the large French dams have been built of uncoursed rubble, the finest stones being reserved for the facing. Dams and walls of reservoirs are often deprived of the water pressure at their backs, and it is therefore necessary to examine their stability under the influence of their weight alone, so that the maximum intensity of the pressure at the inner edge shall not exceed safe limits.

Fig. 6501 gives the profile of a large dam across a river near Poona, in the Bombay Presidency. It is designed by Fife to impound the river-water for irrigation and water-supply purposes.

The masonry, which is rubble stone set in mortar, made from a lime which is somewhat hydraulic, weighs about 150 lbs. a cubic foot. The stone is blue basalt, of a specific gravity of about 2·8 or 2·9. Part of this dam is used as a weir. The value of q for this structure is a little greater than one-fourth.

6501.



6502.

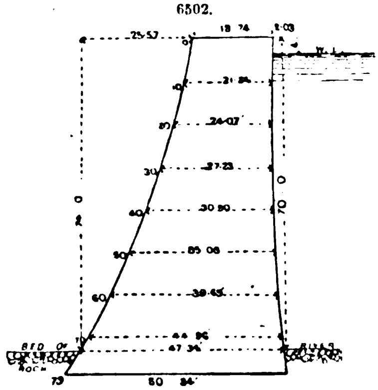


Fig. 6502 is the section of a dam at Toolsee, forming a lake for the water-supply of Bombay.

It is designed by W. J. M. Rankine, and is built of heavy basalt rubble masonry, the lower portions of the wall being set in a mortar of mixed lime and Portland cement, the rest in a mortar from the ordinary Kunker lime of Salsette. For other sections of dams, see Figs. 2247 to 2255.

Harbour, *River*, *Dock*, *and Sea Walls* are subject to the possibility of an infiltration of water behind the masonry, while the water in front has been withdrawn, and the walls must be made strong enough to resist water pressure. Provision must often be made for the contingency of the erection of sheds for merchandise, or even warehouses, and for the storage of heavy goods, during transhipment, on the ground behind dock and wharf walls.

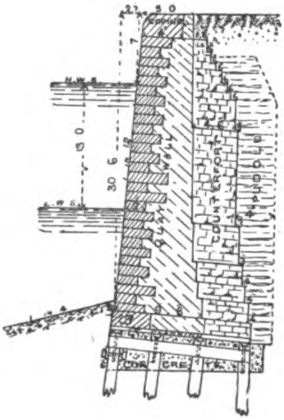
Fig. 6503 is the section of the quay wall at the Dublin graving docks, by Halpin. The wall is faced and coped with granite ashlars. Counterforts, 4 ft. 6 in. by 7 ft. broad, are placed at a distance of 22 ft. from centre to centre. A puddle wall is placed along the back of the work.

Fig. 6504 is a section of the Hartlepool docks harbour wall, designed by John Rennie. Ashlar facing of stone, 2 to 3 ft. long and 15 in. high, is used. Counterforts, 4 ft. by 4 ft. broad, are at 17 ft. distance from centre to centre. The wall is backed with puddle.

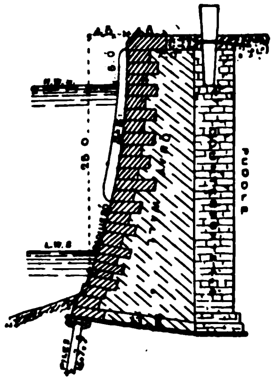
Fig. 6505 is the section designed for the sea wall at Bombay, and used in the Wellington pier-works in that harbour. The wall is built of basalt rubble laid in ordinary lime and Aden pumice mortar, and faced with large stones, 2 to 3 ft. long and 12 in. high, dressed about 6 in. on beds and joints. There are no counterforts or puddle walls behind, and the foundations are con-

crete. This wall has a rather narrow margin of stability, and consequently has shown some slight signs of weakness.

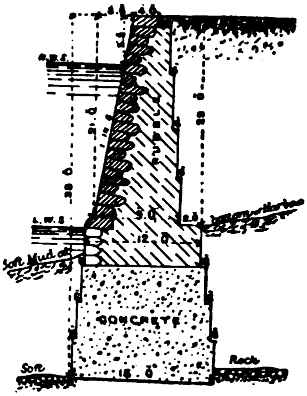
6503.



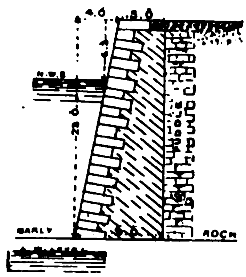
6504.



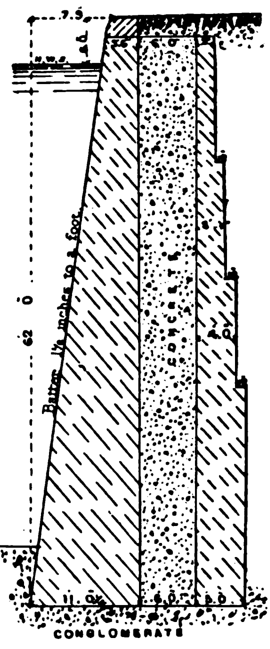
6505.



6506.



6507.



6508.

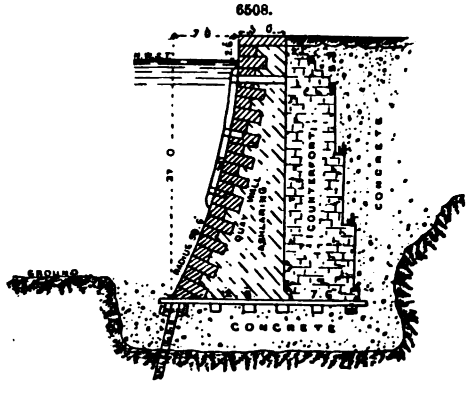


Fig. 6506 represents a wall at the Sunderland docks.

The river wall of the Bristol docks, by Brunlees, is shown by Fig. 6507. It consists of masonry facing, with a core of concrete. The rubble is of stones 12 in. on bed and 4 in. in thickness, with through stones at intervals. The wall is 109 yds. long.

Fig. 6508 is the river wall at the Grangemouth harbour, by John Macneill. It has a curved face, and the counterforts are 5 ft. broad and 24 ft. apart from centre to centre. The wall is founded on, and backed with, concrete. The following is an extract from the specifications of the work;—

"The footings to be in large sizes, the stones not less than from 4 to 5 ft. by 2 to 3 ft., and 12 in. thick, of good tough quality, squared and fair-worked breaking joint with each other.

"The wall to be carried up in courses varying from 12 to 15 in. in thickness, and the sizes to be about 3 ft. 2 in. by 2 ft. for headers, and 3 ft. by 1 ft. 6 in. for stretchers, and to be laid two stretchers to one header, and properly bonded together.

"The whole of the outer stone to be carefully selected as to quality, and to be laid on its natural or quarry bed, the upper and lower bed of every stone to carry its full thickness from front to back, so that the bearing above and below may be perfectly square and level throughout; no pinning in levelling will be allowed; each stone to be brought firmly to its bed by a wooden mallet. The top

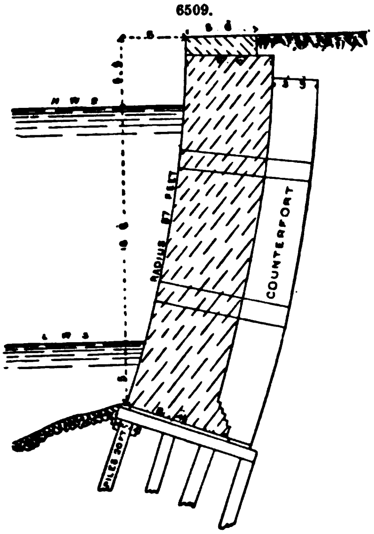
course of stone to wall forming the curb, to be of good whinstone, and to be 12 in. thick, in large sizes, and rounded on the edge, and to be placed round the whole width of wall, and well joggled together. All masonry to be worked with chisel drafts round their faces, beds, joints, and backs, and to be picked between the drafts, so that upon applying a ruler upon the face no part shall be above them, and no more space than $\frac{1}{8}$ in. below them; the outside face being worked with exact regularity and neatness. The whole of the stonework is to be laid throughout on a thick bed of mortar of the following description;—1 measure of good stone lime, 1 measure of pozzolana, 2 measures of sharp clean sand free from rubbish, dirt, and other impurities."

Fig. 6509 is the river wall at Chatham, an example of a brick wall with curved outlines. The counterforts are square and are 15 ft. apart.

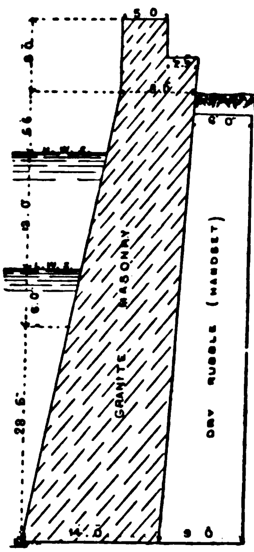
Fig. 6510 is the wall of the pier head, built by the Board of Works, at Kingstown, Dublin.

The masonry is of heavy granite blocks, and the wall is backed with hand-set rubble, laid without mortar.

6509.



6510.



6511.

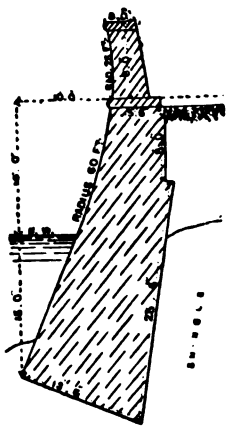


Fig. 6511 is the section of the sea wall at Penmaen Maur, by Robert Stephenson. The facing is of limestone ashlars, set in cement, for 18 in. inwards from the face. This section was adopted after failures.

Retaining Walls and Revetments.—When springs occur behind or below the wall they must be carried away by piping or culverts, and thus got rid of. The masonry at the back of the wall should be left as rough as possible, so as to increase thereby the friction of the earth against it.

Weepers, or rectangular holes about 2 in. wide, are left in the masonry, so as to permit the free escape of any water which may find its way to the back of the wall. In order to secure the more perfect action of these weepers it is usual to place permeable materials, such as shivers and refuse stone, or other waste of the building, or even coarse gravel, in a vertical layer behind the wall. This arrangement avoids the possibility of water pressure at the back, and may, by the extra weight resting on the offsets at the rear, add to the stability of the wall. The angle of repose of the earth filling may be increased, and therefore the thrust reduced by packing it in counter-sloping layers of about 1 ft. in thickness. When the stuff at the back of a wall cannot be thoroughly drained, or when it partakes of the nature of mud, or quicksand, the wall must be designed to resist water pressure, or rather the pressure of a fluid of the density of mud and water combined. An economical method of relieving a wall of such pressure is to tip behind it a bank of sound material, extending as far back as the end of the plane of natural slope; or to build a dry-stone bank between the masonry and the treacherous material.

The thickness of a surcharged wall of vertical rectangular section is obtained from the following formula;—

Let h be the height of wall; c the height of surcharge; x the thickness of a similar wall to sustain a horizontal topped bank of height h; x' the thickness of a similar wall to sustain a bank with an indefinitely long slope or indefinite surcharge, as calculated by equation [25]; then the thickness of required wall, $x_2 = \dfrac{h\,x + 2\,c\,x'}{h + 2\,c}$.

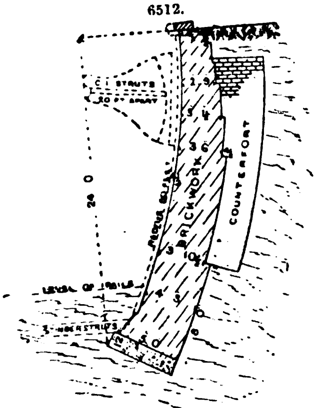
The section adopted for brick walls on the London and Birmingham Railway is shown in Fig. 6512. The counterforts are $4\frac{1}{2}$ ft. wide, and placed at intervals of 20 ft. Pilasters also break forward one-half a brick on the face. The earth at the back was rammed in layers of 1 ft., extending to 6 ft. backwards. These walls began to fail in some instances when the strata sloped down towards the wall, and were supported as shown in the figure by dotted lines; the upper struts being cast-iron ribs, the lower timber balks, extending to the walls on the opposite side of the cutting.

Fig. 6513 is the section of a retaining wall on the Dublin and Kingstown Railway.

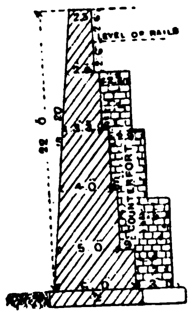
Fig. 6514 is the section of a dry-stone retaining wall, adopted on an Indian ghaut road. The stone is heavy basalt, carefully selected, and set with chip primings.

An example of a surcharged retaining wall is shown in Fig. 6515. The wall is used to support the face of a cutting on the Dublin and Kingstown Railway.

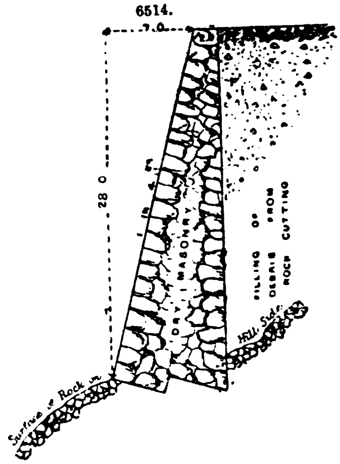
6512.



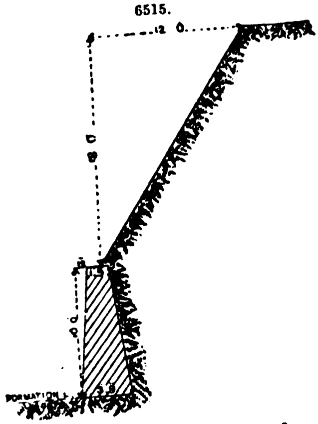
6513.



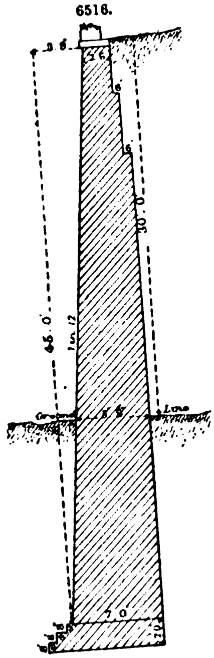
6514.



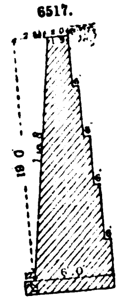
6515.



6516.



6517.



6518.

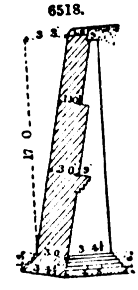


Fig. 6516 is the section of a returned wing wall, that is, a wing carried back into the embankments in a line with the face of the bridge, on the Clydach Valley Railway. A wing wall of this class does not receive the thrust of the whole prism of earth behind, owing to the nearness of the opposite wall, and it is also strengthened by the slope of the embankment which lies outside it.

Fig. 6517 is the section of an ordinary stone wing wall from an example of a bridge on the Great Southern and Western Railway, Ireland.

Fig. 6518 is the section of a brick wing wall. A peculiarity noticeable in this wall is the shelf placed behind to catch the pressure of the earth. The counterforts are 1′ 9″ broad, and are placed 6 ft. 9 in. apart from centre to centre.

Counterforts are projections of the masonry of the back of the wall, occurring at intervals of from 10 to 20 ft. They are generally rectangular in plan and elevation, but they occasionally may be trapezoidal. Counterforts act by their weight in increasing the stability of walls, and as they may be considered to hang on at the back, the bond at their junction with the wall must be carefully attended to, and long headers, with hoop iron in the upper courses, should be used to bind them to the wall. Provided this is attended to, the masonry of the counterfort itself may be of the most economical character. The security, therefore, of their foundations is a matter of secondary importance, as counterforts should be made to depend for support chiefly on their cohesion to the wall. This principle we see frequently carried out in practice at the rear of the abutments of railway bridges, where the foundations of counterforts are placed almost on the surface of the ground under the embankments. In order that the moment of the weight may have the greatest value, counterforts should not receive any batter.

Long thin counterforts are considered to act advantageously by breaking up the pressure of the earth; and Hope conceived that a wall might become a mere shell, exposed to hardly any pressure if the earth were supported by its friction against the sides of long, but thin and frequent, counterforts. The extension of this principle is the introduction of relieving arches, described farther on.

Counterforts are especially useful for military works, where they limit the destructive effect of projectiles to those panels of the wall actually struck. The spacing of counterforts is usually determined by the practice of engineers, which makes it about three times the thickness of the wall between; or, it may be obtained by solving the equation for the stability of a counterforted wall in terms of L for an assumed breadth of wall and given dimensions of counterforts.

Rondelet gives a rule for the dimensions of counterforts that they should have the same length of face c, as the breadth of the wall, and their projection should be twice this dimension. In other words, $c = x_1$ and $z = 2\,x_1$. The stability of a counterforted wall is calculated by taking the sum of the moments of both the panelled and the counterforted portions of the wall round the respective limits of deviation of the resultant from the centre of the base, just as in uniform walls, and dividing the sum by the length of wall. In Figs. 6519, 6520, let L be the length of wall between the counterforts; c the length of one counterfort along the line of the wall; z the thickness of the counterfort perpendicular to the face of the wall; x_1 the thickness of the wall independently of the counterforts.

Then $w_1\,h\,\{\,L\,q\,x^2 + c\,(x + z).q\,(x + z)\,\} = \frac{H\,h}{3}(L + c)$.

$$x_1 = \sqrt{\frac{H}{3\,w_1\,q} - \frac{c\,z^2}{L + c} + \left(\frac{c\,z}{L + c}\right)^2} - \frac{c\,z}{L + c}, \qquad [43]$$

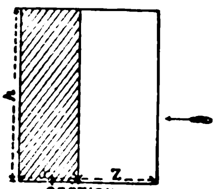
and

$$z = \sqrt{\left(\frac{H - x^2}{3\,w_1\,q}\right)\left(\frac{L + c}{c}\right) + x^2} - x. \qquad [44]$$

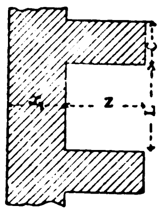
The unit of length is here $L + c$ instead of 1 ft. as in all other cases.

There is always a small saving by the use of counterforts instead of a plain wall of uniform section, the ratio of the quantity of masonry in the former and the latter being $L\,x_1 + c\,(x_1 + z) : (L + c)\,x$ when x is the thickness of the uniform wall.

6519.



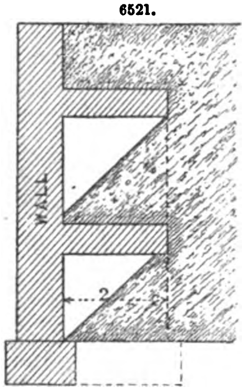
SECTION.



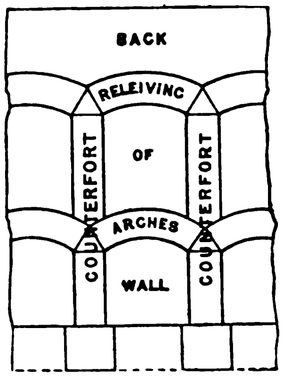
PLAN

6520.

6521.



6522.



Relieving Arches are sometimes built on the counterforts, as piers. Their object is to carry the whole of the superincumbent filling, so that none of the earth pressure may come on the wall, which therefore becomes a mere shell blocking up the faces of the arches. The arches may be in one or more tiers, the length being regulated so that the natural slope of the earth touching the crown of the intrados of the arches shall not cut the back of the wall, over the extrados of the arches in the next tier below. Fig. 6521 represents a section of such wall with two tiers of arches. Fig. 6522 shows the back view of same.

To compute the length of the arches and counterforts, let d be the depth of the crown of the arch below the surface, h_2 its clear height, θ the angle of repose of the earth; then, approximately, the length is

$$z = \text{cotan.}\,\theta\left(h_2 + \frac{d}{(1 + \sin.\,\theta)^2}\right), \qquad [45]$$

and

$$h_2 = z\tan.\,\theta - \frac{d}{(1 + \sin.\,\theta)^2}. \qquad [46]$$

In soft ground the bases of the counterforts may be connected by inverted arches.

Buttresses differ from counterforts in that they are projections placed in front of the wall, and

act by increasing the leverage of the wall. The whole mass tends to turn over the outer edge of the buttresses; therefore the intensity of the pressure throughout their substance is very great; and consequently their foundations should be made very secure, and should present as well the greatest possible resistance to compressibility. The foundation beds, as well as the coursing planes, should be at right angles to the resultant pressure. The masonry should be of the best description, and the form should be triangular, the bond at the junction with the wall being well secured.

Buttresses are more economical than counterforts, but they can only be used where there is a free space in front of the wall, and where the question of space or value of land presents no difficulty. They are also inapplicable in quay and river walls, where face projections would be inconvenient and dangerous to vessels.

The stability of a buttressed wall is thus calculated;—Let L, Figs. 6524, 6525, be the length of wall between buttresses; c the length of buttress along its face; z its thickness or projection from the face; x_2 the thickness of wall. Then for a vertical rectangular section of wall, with triangular buttresses, if the moment be taken round a deviation $q\,z$ from the centre of z,

$$w_1 h \left\{ (L + c)\, x_2 \left(\frac{x_2}{2} + \frac{z}{2} + q\,z \right) + \frac{c\,z}{2} \left(\frac{z}{6} + q\,z \right) = \frac{H\,h}{3} (L + c). \right.$$

$$\therefore \quad x_2 = \sqrt{\frac{2}{3}\frac{H}{w_1} - \frac{1 + 6q}{6} \cdot \frac{c\,z^2}{L + c} + \left\{(q + \tfrac{1}{2})\,z\right\}^2} - (q + \tfrac{1}{2})\,z, \quad [47]$$

and

$$z = \sqrt{\frac{4\,H\,(L + c)}{3\,w_1\,(1 + 6q)} - \frac{6\,x^2\,(L + c)}{(1 + 6q)\,c} + \left\{\frac{3 + 6q}{1 + 6q}\left(\frac{L + c}{c}\right)\right\}^2} - \frac{3 + 6q}{1 + 6q}\,\frac{L + c}{c}. \quad [48]$$

If the buttresses are placed close together, the panel between may be formed by an arch of only a couple of feet in thickness, and of small versed sine. Retaining walls have been so constructed on the Metropolitan railways, Fig. 6523.

The stability of such a structure, Figs. 6524, 6525, may be calculated by the same formula as that used for a buttressed wall without much error; and if the weight of the arch be neglected, the following simple formula may be used for rectangular buttresses; $w_1\,z\,h\,c\,q\,z = \frac{H\,h}{3}(L + c)$,

$$\therefore \quad z = \sqrt{\frac{H}{3\,w_1\,q} \cdot \frac{L + c}{c}}.$$

For triangular buttresses;—

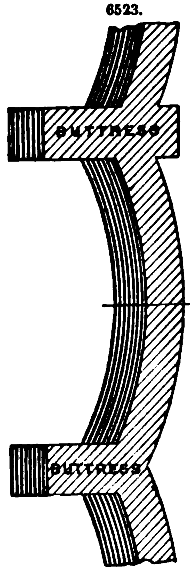
$$z = \sqrt{\frac{4\,H}{w_1\,(1 + 6q)} \cdot \frac{L + c}{c}}.$$

If the weight of the arch is taken into account, the formulæ [47] and [48] may be used without appreciable error.

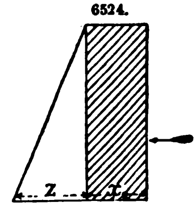
Land-ties and Struts are of the nature of artificial counterforts and buttresses, and have been adopted as a supplementary measure to strengthen walls which have shown symptoms of failure.

Land-ties act as anchors at the backs of walls, and consist of iron bolts passing through the masonry, and attached to the centre of pressure of large iron plates imbedded in the solid earth behind the wall, the pressure being distributed over the face of the wall by broad washers.

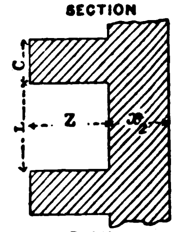
6523.



6524.



SECTION



PLAN
6525.

When intended entirely to resist the sliding of the wall, land-ties are fastened at one-third the height of the wall; but if the sliding is to be resisted equally by ties and the foundations, they should be placed at two-thirds the height above the base. Their position is therefore indicated by the symptoms of failure observed.

The following represents the holding power of land-ties;—Let W be the weight of a cubic foot of the earth; θ the angle of repose; d_1 and d respectively the depth of the upper and lower edges of the plate below the surface; R the holding power in pounds a foot in breadth of plate, $= W\,\frac{d^2 - d^2}{2} \cdot \frac{4\,\sin.\,\theta}{\cos.\,2\,\theta}$, and the position of the centre of pressure of the plates at which point the rods should be attached, is $\frac{2}{3}\,\frac{d^3 - d_1^{\,3}}{d^2 - d_1^{\,2}}$, measured from the surface of the ground.

Struts, either of masonry or cast iron, may be used to prevent a wall from coming forward. They may abut against a mass of masonry sunk in the ground in front of the wall, or if in cuttings, against the opposite wall. Those strutting the foundations may take the form of inverted arches, while the upper parts of the wall may be held apart by arched ribs of large curvature, springing at a point two-thirds of the height from the base. The expediency of adopting this method of adding to the stability of a wall as a primary design, should be determined by the cost of such

work considered in relation to the value of the land adjoining. Hoskins proposed brick arches below and above, the upper strut arch having an inverted arch over it to keep it down at the crown; and he shows in a paper read at the Institution of Civil Engineers that for a double line of railway of 4 ft. 8½ in. gauge, in 65-ft. cutting, the arrangement he proposed would save nearly one-third the cost. The principle of masonry arched struts was introduced by A. J. Adie in the Chorley cutting, on the Bolton and Preston Railway, where, in a 60-ft. sand cutting, he used walls 20 ft. high, one-fifth the height as breadth at base, a batter of 2 ft., and buttresses 2 ft. 6 in., with rubble strut arches at 16½ ft. intervals. Cast-iron arched struts braced at the crown were used to support the failing walls on the London and North-Western Railway, and were adopted in the original construction of the retaining walls of the London Metropolitan Railway where the line passes through deep open cuttings.

See Dam. Harbour. Masonry.

Books on Retaining Walls;—Moseley's 'Mechanics of Engineering and Architecture.' Weisbach's 'Principles of Mechanics.' Mahon, 'Civil Engineering,' by Barlow. Rankine's 'Civil Engineering and Applied Mechanics.' Scheffler, 'Traite de Stabilité des Constructions.' Murray's 'Treatise on the Stability of Retaining Walls.' Neville's paper in vol. 1 of 'Transactions C. E. Inst., Ireland.' Jacob (A.), 'Practical Designing of Retaining Walls.' Dempsey's 'Practical Railway Engineer.' Professional papers of Indian Engineering—papers therein on Retaining Walls, by J. H. E. Hart, and others.

RIVERS. Fr., *Rivières*; Ger., *Flüsse*; Ital., *Fiume*; Span., *Rios*.

Rivers are natural water-courses which drain the tracts of country through which they flow. Hence their magnitude depends on the extent of the basin which they drain; and the volume of water which they discharge at any given time varies with the amount of rainfall immediately preceding that time. In this they differ from canals, which, being supplied with water chiefly by artificial means, preserve a nearly constant volume. Rivers differ from canals also in being of irregular section and varying inclination; and as their course has been determined by the action of their own water constantly tending to a lower level under the influence of gravity, it presents a continual succession of sinuosities and other irregular features which do not exist in canals. Moreover, as many of them discharge directly into the sea, they may be exposed to tidal influences in those portions which are in immediate proximity thereto.

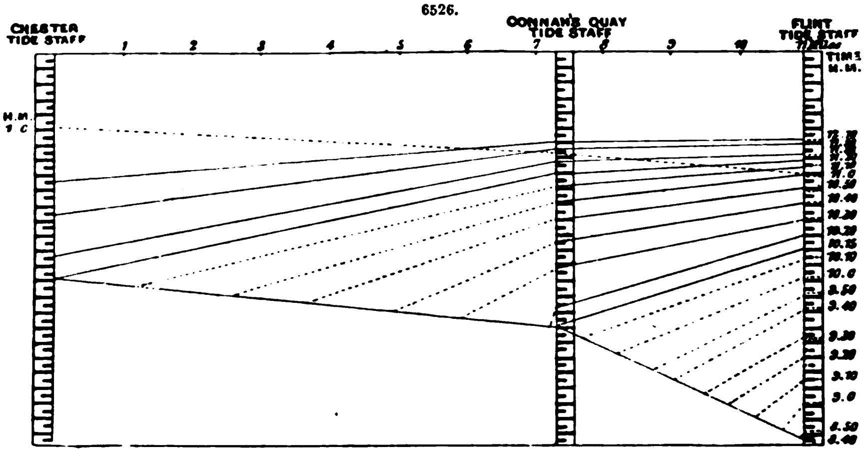
From an engineering point of view a river consists of two distinct portions, the upper, or river proper, and the lower, or tidal portion; for the works required for the improvement and conservation of each of these divisions are of a totally distinct character. In the river proper, these works consist chiefly of embankments for protecting the adjacent lands from floods, of piling, walling, and other means for protecting the banks from the corroding action of the stream, and of weirs thrown across the stream for the purpose of forming stretches of canal, with cuts and locks to connect the different reaches. In the tidal portion the works are of a more varied and extensive character, and consist in widening and deepening the bed, and in straightening the course of the river, in the removal of bars and shoals, and the construction of walls to guide the tidal current, and in the formation of new cuts, and the closing of subsidiary channels. We shall treat these divisions separately, and shall consider first the upper portion or river proper. Before any engineering work connected with rivers can be designed and the cost estimated, it is necessary to possess full and accurate data respecting the velocity and the discharge of the river in question, the form and nature of its bed and banks, its slope and width, with various other information bearing on the subject, especially that to be derived from tidal observations. These data can be acquired only by means of careful and minute surveys, soundings, probings, and borings, and an extended series of observations on the influence of tides and floods. We shall therefore consider briefly these means of obtaining the necessary preliminary information before entering on the subject of the works themselves, omitting, however, the details of triangulation and determining of base lines for the purpose of obtaining the plan of a river. These matters belong to surveying in general, and they will be more appropriately treated of in another place.

In the tidal portion of a river the level of the water is constantly changing. If this change of level were uniform and showed itself simultaneously throughout the whole of the tidal portion, that is, if the level rose or fell to the same degree at every point at the same instant, a very limited series of observations would be sufficient to enable us to determine accurately the form, inclination, and character of the bed of a river, with other data necessary to the designing and executing of engineering works. Such, however, is far from being the case, and any estimates made on that assumption would be liable to serious error. When the level at the mouth of a river begins to rise in consequence of the returning tide, it does not immediately influence the descending stream above; the latter continues for some time to descend with the same velocity as when the level at the mouth was at its lowest point, and this velocity is checked only gradually from the mouth upwards. The consequence is that near the mouth of the river the water becomes heaped up, being held above its natural level by the dynamic force of the descending stream. As this force is gradually overcome the elevated level ascends the river. But before it has reached a very considerable distance up the stream, the tide again recedes from the mouth and the water there heaped up flows out to sea, thus producing a declivity in the opposite direction. In this way, in very large rivers, there may be several tides in the river at one time, as in the Amazon, for example. But in the comparatively small rivers of Europe, we shall hardly find the influence of more than one tide. If the above were the only disturbing agencies, we should still have some degree of regularity and uniformity that would enable us to determine from the ascertained influences at work in one river the character and extent of those in another. Other agencies, however, do exist, and they often exert a powerfully disturbing influence. These are chiefly sudden widenings and contractions of the stream and abrupt turns, and the form and extent of the mouth which receives the tidal wave. As no two rivers are alike in these respects, it is necessary to make in every case an extended series of observations in order to determine accurately the degree of tidal influence at any given point.

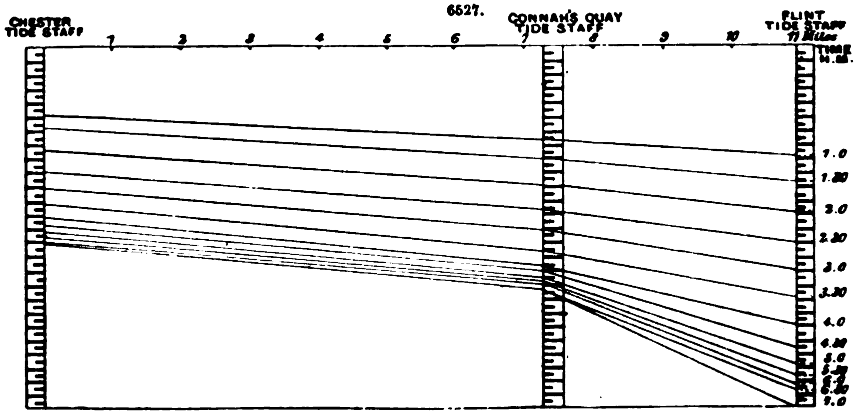
As an illustration of the preceding remarks we give an example from Stevenson. The observa-

tions made by him on the river Dee, between Flint and Chester, a distance of eleven miles, show conclusively the existence of the elevated level and the necessity for accurately ascertaining the form and position of the tidal lines. Fig. 6526 shows the height of the tide at Flint, Connah's Quay, and Chester at a given time. The full lines are those which were ascertained by observation; the dotted lines indicate the probable direction when, for want of additional stations, they could not be certainly determined.

6526.



6527.



6528.

The tide, as will be seen from the figure, began to rise at Flint at 8 hours 40 minutes; at 10 hours 15 minutes it had risen 12 ft. 8 in., and at that time had just appeared at Connah's Quay, the surface of the water at Flint being 5 ft. 4 in. above that at Connah's Quay. At 11 hours 20 minutes the tide had risen 18 ft. 4 in. at Flint, and was one foot above the level of the water at Connah's Quay, and 7 ft. 10 in. above that at Chester, where the tide had just begun to appear. Thus, while at low water there is a fall of 11 ft. from Chester to Flint, there was, at the time above mentioned, a fall of no less than 7 ft. 10 in. on the surface of the water from Flint to Chester. At 12 hours 10 minutes it was high water at Flint, and at that time there was a fall of 1 ft. 7 in. to Chester; but the high water at Chester did not occur till one o'clock, by which time the water at Flint had fallen 2 ft. 2 in., and the fall on the surface of the water from Chester to Flint was 3 ft. 1 in. Fig. 6527 shows the lines of ebb tide on the same day. It will be seen by referring to this figure that the water subsides gradually, and that the tidal lines approach much more nearly to parallelism and horizontality than during flood tide. The upper lines of these figures correspond with the tidal line when it is high water at Chester.

These facts show the necessity of carefully observing the effects of the tide previous to undertaking soundings and borings in the tidal portion of a river. A simple and effective mode of conducting these observations is to erect at proper intervals throughout the portion to be surveyed a number of tide-gauges similar to that shown in Fig. 6528. These are merely 1½-in. planks, from 5 to 7 in. broad, and graduated to feet, halves and quarters. A more minute division would only prove embarrassing to the observer, especially when the gauge is situate some distance from the bank. Considerable judgment is required to select proper stations for these gauges. Disturbing influences, such as enlargements and contractions of the streams, bends, inequalities of bed, and exposure to the action of the wind must be considered and the gauge placed so as to detect and correct them. In selecting a station, care should be taken to place the gauge in a conspicuous position, that is, with a bank, quay, wall, or other structure as a back-ground, so that the divisions may be clearly seen. Of course, the greater the number of stations, the more correct will the result of the observations be; but it is hardly practicable to multiply them beyond a very limited

number, by reason of the difficulty of obtaining and superintending a large number of men to make the observations. For it is evident that unless the work is carefully performed and precautions taken to correct variations of time among the numerous observers, the results must be erroneous. For this reason, it is better to have only a few well-selected stations, and to make the soundings during the ebb when, as the example quoted above shows, the lines are more nearly parallel. The observations should extend over a period of twelve hours at least, and they should be taken every ten minutes, and entered in a book provided for that purpose. When a sufficient number of observations have been made, it only remains to ascertain the relative levels of the gauges. This is an ordinary levelling operation, but it requires great care, and, to avoid error, should be performed at least twice.

We shall now show how these tide-gauges are made use of to correct the depths of the soundings. The datum line to which the depths are reduced is usually that of high water of an ordinary spring tide. Let D be the height of this line upon the gauge. Suppose now a sounding taken near the gauge, and let d be the depth of that sounding. If H be the height of the water upon the gauge at the time when the sounding is taken, the corrected or reduced depth $\delta = d + (D - H)$. When H exceeds D, which may happen in the case of an equinoctial tide, the formula becomes $\delta = d + (H - D)$. This formula gives true results for depths near the gauges, but might lead to considerable error in those at a distance from the gauge, in consequence of the tidal lines not being parallel to the line of high water. The obvious remedy for this is to increase the number of gauges; but as we have already pointed out, there exist difficulties which render this impracticable. The only means of avoiding a liability to error in this respect is to take the soundings during the ebb when, as the above example shows, the tidal lines are most nearly parallel to high water.

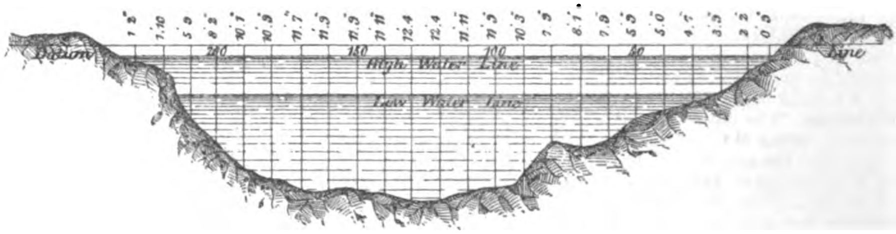
The method of taking the soundings is very simple, but it demands great care on the part of the operators, as slight errors of observation may occasion serious errors in the protraction of the work. To perform the operation satisfactorily, a boat is requisite, manned by three men, two to row the boat, and the third to steer her straight across by keeping two objects on the opposite bank in line. One observer is then free to take the soundings, and the other to observe the angles for the purpose of fixing the positions and to register the soundings. When the depths do not exceed 10 ft., a light iron rod is preferable to a line to sound with; it should be graduated in the same way as the tide-gauge described above. The soundings should be taken in straight lines across the river, the distance of the soundings apart as well as that of the lines of soundings, being determined by the degree of accuracy required. It is, however, in all cases desirable to take them more frequently in the low-water bed of the river than between that and the shore, as this gives the greatest navigable depths, shows the rise of the tide, and is required in the longitudinal section. Sextant observations are requisite to fix the positions of the lines of soundings. When the river is narrow, it will be sufficient to fix the extremities only; but in broad estuaries, several observations will be required along each line. The mode of registering the observations and soundings in the field-book is as follows;—

Stations.	Angles.	Time.	Depth.	Height of Tide on A Tide-gauge.	Reduced Depths.	Remarks.
	deg. min.	h. m.	ft. in.	ft. in.	ft. in.	Datum high water on A tide-gauge 3 ft. 10 in.
Station X	113 17					
Station Y	68 8	9 20	1 5	3 1	2 2	Rock bottom.
Station Z	43 27					
		9 25	3 0	3 1	3 9	„
		9 31	3 9	3 0	4 7	„
		9 36	4 2	3 0	5 0	„
		9 41	4 10	2 11	5 9	„
		9 47	6 9	2 10	7 9	„
		9 52	7 1	2 10	8 1	„
		9 57	6 8	2 9	7 9	„
		10 3	9 1	2 8	10 3	„
		10 9	10 7	2 8	11 9	Gravel.
		10 17	10 8	2 7	11 11	„
		10 24	11 0	2 6	12 4	„
		10 31	10 11	2 5	12 4	„
		10 37	10 6	2 5	11 11	„
		10 45	10 3	2 4	11 9	„
		10 51	10 2	2 3	11 9	„
		10 58	9 11	2 2	11 7	„
		11 4	9 0	2 1	10 9	„
		11 12	8 3	2 0	10 1	„
		11 18	6 4	2 0	8 2	„
		11 25	3 10	1 11	5 9	„

In the above register only one observation is recorded. It would be necessary, however, to take another at the opposite bank, at least; but generally it would be desirable to take one at every four or five soundings. In some cases, it is requisite to take an observation at every sounding. The fall from the datum line to the surface of the water is ascertained by the ordinary process of levelling. Fig. 6529 is the section of the river, as protracted from the above register. In order to reduce the soundings to low water, and to determine the height of sand-banks above the low-water

line, a line should be taken at low water along the middle of the low-water channel, throughout the whole extent of the survey. This is done by rowing gently down the stream and taking the soundings at regular intervals in the manner described above. The intervals may be determined with sufficient accuracy by counting the strokes of the oars.

6529.



One of the most important preliminary observations connected with the execution of hydraulic engineering works is the determination of the cross-sections of the bed of a river by boring or probing. For it is by this means that the nature of the bed is ascertained. In deepening a river, for example, it furnishes the data for determining the line of the excavation, the most suitable means of executing the work, and the probable cost. And in selecting a site for a pier, or other engineering structure, boring constitutes the only available means of ascertaining the form and composition of the ground which is to serve as the foundation.

The mode of carrying out borings of this nature is very simple; but it demands the greatest care to avoid erroneous results. And it must be borne in mind that a slight error committed in this operation may lead to very serious consequences. The most convenient time for making the borings is at low water. The places at which the borings are to be made and the intervals apart should be all determined before beginning the actual operations. In making the selection, the engineer must be guided by the objects of his investigations and the character of the river's bed. When the survey is made solely with reference to the improvement of the navigation, sections are, in general, required only where fords or shoals occur, and in such cases one or more lines of section will be decided upon, according to the extent of the shoal. In other cases, where the bed is irregular, and rock is found at intervals, either bare or covered with a few feet of sand and gravel, numerous sections will be necessary. The positions of the lines of section should be marked by a stake, which stake should be placed with reference to the datum employed for the soundings, so that the depths of the borings may be referred to that datum. It will be necessary in all cases to erect a tide-gauge previous to commencing boring operations to indicate any change of level that may occur while the work is being carried on.

A section of the bank from the stake to the edge of the water is first made in the usual way with the spirit level and rod. The borings are then taken at intervals of 10 ft. and upwards, according to the nature of the bed and the object of the inquiry. To ensure accuracy and uniformity in the intervals, some engineers stretch a cord, graduated to the proper intervals, across the river, and support it upon rods driven into the bed of the river for that pupose; the section of the opposite bank from the water's edge to the high-water line is made in the same way as the first portion.

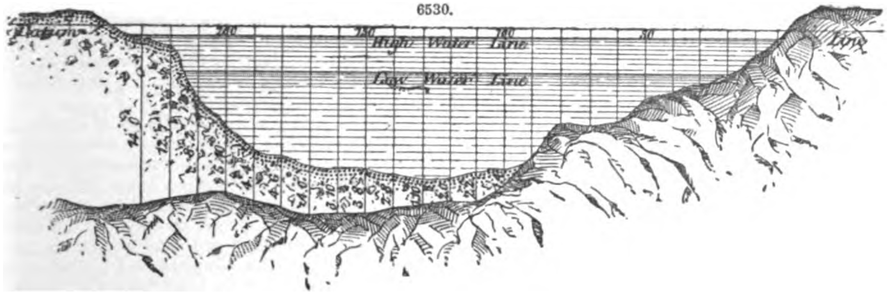
The borings, or more strictly speaking, probings of the bed of the river are made with iron rods 1¼ in. in diameter and about 18 ft. in length. They should be steeled at the points, and graduated to feet, half-feet, and quarters with chisel marks. The mode of working these rods is to *jump* them into the bed of the river from boats, unless the material to be bored through be too hard to admit of this, in which case they are driven with a light hammer. When a difficulty is found in extricating them, a purchase may be applied from the side of the boat.

The depths of the borings must be registered as they are taken, and afterwards corrected with respect to the datum. To ascertain the depth of the boring, it is only necessary to deduct that of the water from the total length of rod immersed. The following is the manner of keeping the field-book usually adopted, the fall from the datum line to low water being 3 ft. 9 in.;—

Depth of Water.	Corrected Depth of Water below Datum.	Distances.	Corrected Depth of Boring below Datum.	Depth of Boring.	
ft. in.	ft. in.	feet.	ft. in.	ft. in.	
8 0	11 9	100	13 1	1 4	through gravel to rock.
8 2	11 11	110	14 1	2 2	„ „
8 7	12 4	120	14 4	2 0	„ „
8 7	12 4	130	14 2	1 10	„ „
8 2	11 11	140	14 7	2 8	„ „
8 0	11 9	150	15 5	3 8	„ „
8 0	11 9	160	15 7	3 10	„ „
7 10	11 7	170	15 7	4 0	„ „
7 0	10 9	180	15 3	4 6	„ „
6 4	10 1	190	14 5	4 4	„ „
4 5	8 2	200	14 0	5 10	„ „
2 0	5 9	210	13 11	8 2	„ „

The borings in this case are upon the same line of section as the soundings in the last figure. Fig. 6530 is the section as protracted from the above register. The borings were continued from the low-water to the high-water line.

6530.



The discharge of a stream is usually estimated by the number of cubic feet of water that passes along its channel in a given time, as one second. To determine this quantity, it is necessary to ascertain the mean velocity of the stream, the discharge being equal to the product of the area of the section by the mean velocity. The area of the section is found by the soundings; but it is essential to accuracy when computing the discharge, to select a section at a point in the stream where the equable flow of the water is not disturbed by great irregularities of the bed, or by unusual impediments. The velocity of a stream is greatest at the surface and at that point in the surface which is situate over the greatest depth. It decreases gradually towards the bed and the banks in consequence of the friction of the water upon their surfaces. When the section of a stream is uniform, the mean velocity may be deduced at once from the greatest velocity by a simple formula. In rivers, however, we never get a uniform section, and it becomes, therefore, necessary to find, by direct experiment, the greatest velocities at several points in the breadth of the stream. The section obtained by the soundings shows the breadth divided into a number of equal lengths by the lines of sounding. We have, then, only to find the greatest or surface velocity in the middle of each of these lengths, and to deduce from it the mean velocity in that portion of the stream which is enclosed by the two sounding lines. The area of this portion multiplied by the mean velocity will give the discharge in that portion or compartment of the section. The sum of the products of all these elementary areas by the elementary mean velocities, or the product of the total area of cross-section by the mean velocity, as a mean of all the elementary velocities, will be approximatively the discharge of the river. We say *approximatively*, because it is impossible to obtain a formula that shall give the mean velocity exactly under all circumstances. In large rivers the mean will be higher than in small streams, and there will always be local disturbing influences, the action of which cannot be included in the expression of any general formula. It is obvious that the approximation will be in proportion to the smallness of the divisions or elementary areas described above; but in practice it is seldom necessary to determine the discharge with great precision. It will generally be sufficient, when the soundings are taken at small intervals, to make the area between three soundings the elementary area, and to determine the velocity at every second sounding.

Several means are employed to determine the surface velocity. The most simple is to note the time of transit of floating bodies over known distances. For this purpose, very light bodies must be selected. But this method is liable to error, by reason of the irregularities and eddies of the current, caused by irregularities of the bed, and by the influence of the wind upon the float. There are also difficulties in employing this method on broad rivers where the float cannot be observed from the banks. A more trustworthy means of ascertaining the velocity is the tachometer. This is a small instrument provided with fans, like those of a windmill, to which motion is communicated by the water. The velocity is deduced from the number of revolutions of the axle. This instrument can be used at any depth. A still more accurate instrument is Pitot's tube as modified by Darcy. We have fully described it in the article Hydraulics. Like the preceding, it may be used for any depth.

When the surface velocities have been ascertained, the next step is to reduce them to mean velocities. This is readily effected by means of the following rule, due to Dubuat;—

"If unity be taken from the square root of the surface velocity, expressed in inches a second, the square of the remainder is the velocity at the bottom, and the mean velocity is half the sum of these two."

Thus, let a be the surface velocity, β the bottom velocity, and γ the mean velocity, all in inches. Then $\beta = (\sqrt{a} - 1)^2$, and $\gamma = \dfrac{a + \beta}{2}$. Hence we have the following formula for deducing the mean velocity directly from that observed at the surface; $\gamma = \dfrac{a + (\sqrt{a} - 1)^2}{2}$.

By means of the tachometer, or Darcy's gauge, the mean velocity in each of the divisions or partial areas of the section may be determined without the aid of formulæ. To do this, it is only necessary to measure the velocity at several points in the depth of the stream and to take the mean.

When a close approximation to the true discharge is not desired, the quantity may be found from formulæ, without resorting to the actual measurements described above. By this method the mean velocity is computed from certain measured quantities of which it is a function. There are two classes of formulæ proposed for this purpose. Those of one class are based upon the supposition

of uniform motion, and those of the other class upon that of permanent motion. The former requires that the cross-section of the channel shall be invariable and the slope of the fluid surface constant. In other words, if we suppose the stream divided into straight filaments, parallel to the direction of its motion, the velocity may vary for different filaments, but not at different points in the same filament. According to the theory of permanent motion, on the contrary, the cross-section and slope of the fluid surface may vary, but the discharge through the different cross-sections must be identical; that is, the stream is supposed to be divided into filaments parallel to the general direction of the motion, varying from point to point in diameter, and therefore in velocity, but unvarying in discharge.

Evidently the latter supposition is more in conformity with the actual condition of rivers, but the formulæ which are based upon it differ from those for uniform motion only in containing an expression that takes into account the changes of vis viva caused by changes of cross-section. Consequently, if these variations of cross-section are unknown, the only distinctive terms between the two formulæ disappear. As this is generally the case, formulæ for uniform motion are almost exclusively employed. Numerous formulæ of this class have been proposed by eminent hydraulic engineers, and it must be confessed that the results obtained from them are conflicting. Some of them, however, give results pretty near the truth. Among these, the simplest and probably the most accurate, is that of Chezy, and it is the one now generally adopted for large bodies of water in rapid motion. This formula is the following; $V = B \sqrt{r\,s}$, in which V is the main velocity of the river in feet a second, r the hydraulic mean depth, s the sine of the slope, or the fall of the water surface in one English foot, considering the channel straight and nearly uniform, and B a certain coefficient.

The value of B as adopted by Chezy is not known, as it is not found in any of his papers; but several different values have been assigned to it by subsequent engineers. Thus Young, for large streams, adopts 84·3, Eytelwein, 90·4. D'Aubuisson, for velocities over 2 ft., used 95·6. Leslie, for small streams, adopts 68, and for large streams 100. Beardmore uses 94·2. Neville, for straight, rapid rivers, with a velocity of 1·5 ft., adopts 92·3, and for greater velocities 93·3. Stevenson, for small streams, adopts 69, and for large streams 96. It will be seen from this that considerable diversity of opinion exists concerning the value to be assigned to B. The reason of this lies in the fact that what is true for a perfectly uniform channel, like that prepared for purposes of experiments, is not true for an irregular channel like the natural bed of a river; and engineers in trying to adapt the value of the coefficient found for the uniform channel to the requirements of a natural river, have been thrown back upon their own experience. And as no uniformity exists among those numerous influences which affect the flow of a natural stream, none was to be expected in the conclusions arrived at. What, for instance, has been found to be true of the Mississippi, may be far from the truth in the case of such a river as the Thames. Hence the discrepancy shown in the values of B as determined by different authorities. A value, however, which will give a very closely approximative result when applied to the rivers of England, is 89. With this coefficient, the formula becomes $89 \sqrt{r\,s}$, from which the discharge of the river may be easily calculated.

It may be necessary to remark that care should be taken when gauging a river in a portion that is within the influence of the tide that no under-currents exist, as these would vitiate the results obtained from the mean velocity. The existence of under-currents may be ascertained by means of the instruments already described.

The velocity of a stream is closely related to the stability of its channel. The wearing action of the current, against which it is one of the chief objects of engineering works to protect the banks, is dependent on the velocity of the water and the nature of the materials through which the channel passes. Some interesting experiments made by Dubuat show the relation existing between the velocity of the current and the stability of the channel, from various substances. He found that the greatest velocities close to the bed consistent with the stability of the following materials are—

For Soft clay	0·25 foot a second.
„ Fine sand	0·50 „ „
„ Coarse sand, and gravel as large as peas	0·70 „ „
„ Gravel as large as French beans	1·00 „ „
„ Gravel 1 in. in diameter	2·25 feet a second.
„ Pebbles 1½ in. in diameter	3·33 „ „
„ Heavy shingle	4·00 „ „
„ Soft rock	4·50 „ „
„ Rock, various kinds of	6·00 „ „ and upwards.

When the bed of a river is composed of such materials that the greatest velocity of the current at times of flood is insufficient to set them in motion, the channel is said to be in a permanently stable condition. If the materials are of such a nature that the current is sufficient to move them only when swollen by flood-waters, the condition of the channel is described as stable. And when the materials are unable to resist the force of the current at ordinary times, the condition of the channel is unstable. Dubuat has shown that the bed of a river in an unstable condition presents a series of transverse ridges having a gentle slope on the up-stream side and a rapid slope on the down-stream side. The particles of matter, whether of clay or sand, are rolled up the gentle slope to the summit of the ridge, whence they fall into the next furrow. Here they remain until the removal of the whole of the preceding ridge leaves them again exposed. The motion of the particles produced in this way is much more rapid than we might suppose. Dubuat's experiments showed that with a velocity of 1 ft. a second sand travelled in the manner described above at the rate of about 19 ft. in twenty-four hours.

When the banks of a river are unstable, the course of the channel is continually undergoing

change. If we suppose the course originally straight, it is evident that it cannot long remain so, for a very slight obstacle is sufficient to cause a deviation of the current, which is thus directed against the opposite bank. This bank being unstable, is gradually scooped out at that point by the action of the current, and the earthy matter held in mechanical suspension by the water is gradually deposited in the stiller portion of the stream against the other bank. Thus, while one bank becomes more concave, the other becomes more convex, and in this way a bend is established. On issuing from this bend, the current is directed against the opposite bank, and another bend is established in the contrary direction. This action is continually repeated down the stream, and is one of the causes of the sinuosity noticeable in the course of rivers. It is also evident that this sinuosity must go on increasing until stable ground is met with.

There is also another influence to which we must call attention, namely, the constant tendency of a stream to widen its bed. Other things being equal, the sides of a water channel resist the action of the current less than the bottom. But independently of this action, the banks are exposed to that of atmospheric influences as well as to that of gravity; hence they crumble and fall, whilst the same action of gravity pressing the materials that form the bed upon those lying beneath, increases the friction, and so renders their displacement more difficult. Moreover, the earthy matters that fall from the banks are swept away by the current, leaving the gravelly portion to increase the stability of the bed. Thus the breadth of the bed of a river at any given point will, comparatively to its depth, be in proportion to the stability of the ground at that point.

It must be borne in mind that the sinuosities of a river alluded to above, by increasing the length of the channel upon the same absolute slope, diminish the relative slope and consequently the velocity of the current. The flow of the fluid mass being retarded, its breadth and height of surface will be increased, and hence may result inundations and injury to property. The diminished velocity also tends to establish equality between the force of the current and the resistance of the materials of which the bed is composed, and thus to promote stability.

Intimately connected with the stability of a river's channel is the relation which exists between the velocity of its current and the weight of the particles of solid matter held in mechanical suspension. It has been remarked that the earthy matter scooped out from the bank by the force of the current directed against it was deposited in other places where the velocity was less. Also the beds of rivers, except in parts where the velocity of the water is very great, are composed of particles which have been brought down by the stream. As this deposition of matter changes the configuration of a water channel, it is important to know how rapidly it may go on, and how long it may continue. This is, indeed, one of the questions which, at the outset, claim the attention of the engineer engaged in designing river improvements. The earthy materials brought down by the water are obtained from two sources. The first of these is the banks of the river and of its feeders. The particles seized upon by the current are carried along until they are whirled into a part out of the force of the current or until they come to a part of the river in which the velocity is reduced, where they are deposited. The heavier portions will thus soon come to rest; the remainder, however, may never be deposited in the river at all, as the velocity may in no part be sufficiently reduced to allow the deposition to take place; for the water never being charged to its maximum carrying capacity from this source alone, a considerable reduction of velocity is necessary to cause deposition.

The second and chief source of sedimentary matter is the surface of the country drained by the river. The matters obtained from this source are brought down the streams by flood-waters, that is, by the surface water which finds its way into them. The quantity of sedimentary matter poured into a river from this source may be imagined when we consider the turbid character of surface water, especially after periods of drought. Thus, in times of flood the river may be charged fully up to its maximum capacity. Dupuit has demonstrated that the power of suspension is due to the fact that the different layers of water are actuated by different velocities, and thus exert different pressures upon different sides of the suspended atoms. Hence the greater the difference in the velocities of consecutive layers, the greater will be the power of suspension. Now it has been conclusively proved by direct measurements that the change of velocity from layer to layer is, in horizontal planes, greatest near the banks and least near the thread of the current; and in vertical planes parallel to the current, greatest near the bottom and surface, and least at a point about 0·3 of the depth below the surface, where the absolute velocity has its greatest value. Consequently, if the water be charged to its maximum capacity with sedimentary matter, the greatest amount will be found near the banks and near the surface and bottom, and the least amount near the thread of the current and near the layer 0·3 of the depth beneath the surface. If, on the contrary, the water be under-charged, the distribution of sediment will follow no law, and excepting the part near the bottom where, by reason of the suspending power being much greater there than elsewhere, there will always be an accumulation of matter, the quantity at any point will be determined by the accidental circumstances of eddies and other interruptions to the flow.

When a stream is charged with sediment to its maximum capacity, it is evident that the slightest reduction of its velocity will cause deposition. Thus, a projection of the bank, a bend, the abutments of a bridge, or any similar impediment to the current, causes a diminution of velocity in that portion of the stream which is most heavily charged with sediment, and the space above the impediment, as far as its influence extends, silts up. An increase of breadth in the river channel reduces the velocity of the whole current, and the suspended matter is deposited over the whole bed; thus the height of the bed becomes raised. But, as we have seen, the suspended matters are not equally distributed over the stream, and therefore they are not deposited equally over the bed. Hence are produced deviations and divisions of the current, shoals, and frequently inundations.

This silting up of river channels is one of the chief questions claiming the attention of the engineer who proposes altering the channel in any way; and he should ascertain, previously to designing any work that will affect the flow of the current, the quantity of sedimentary matter held in suspension by the water, both when the river is in its normal and when it is in an abnormal

condition, so as to be able to determine beforehand the effect of reducing the velocity in any part of the stream. Whether or not the stream is charged to its maximum capacity will be shown by the existence or the non-existence of the conditions we have mentioned. A simple and trustworthy means of ascertaining the quantity of sediment in a stream is that employed by the engineers commissioned by the American Government to survey the Mississippi. For these experiments three stations were selected, two near the banks, and one in the middle of the river. Samples of water were collected daily at surface, mid-depth, and bottom. These samples were secured in a small keg, heavily weighted at the bottom and provided at each of its heads with a large valve, opening upward. These valves allowed a free passage to the water while the keg was sinking to the required depth, but prevented its escape while being drawn up. When the keg reached the surface, the water contained in it was thoroughly stirred and a bottle filled from it. On returning to the office, 100 grammes of water were accurately measured from each of the samples, and each parcel separately preserved in a precipitating bottle. After receiving six days' contributions, these bottles were set aside for two weeks to settle. The greater part of the water, then perfectly clear, was removed by a siphon. The remainder, after thorough shaking, was poured upon a double filter composed of two pieces of filtering paper of exactly equal weight. After becoming quite dry, the two papers were separated and placed—one containing all the sediment of the 600 grammes of river-water, and the other perfectly pure—in opposite sides of a very delicate balance. The difference of weight, which was, of course, the exact weight of the sediment, was then accurately ascertained. These elaborate experiments were continued for fifty-two weeks, with the following mean results;—For the two outer positions, surface, ·291 gramme; mid-depth, ·330 gramme; bottom, ·379 gramme. For the middle position, surface, ·291 gramme; mid-depth, ·365 gramme; bottom, ·376 gramme. Total, 2·042 grammes of sediment in 600 grammes of water, or ·34 per cent. These results show that the water of the Mississippi is never charged to its maximum capacity. The above method of ascertaining the quantity of matter in suspension may be readily applied to all rivers. It will be sufficient for practical purposes to take three samples a day for two consecutive days when the river is at ordinary summer level, and the same number for three consecutive days when the river is in flood.

We have now pointed out the several agencies which tend to produce defects in a river channel, and have described briefly their mode of action. Against these agencies the engineer has to contend; and to contend successfully, he must acquire a complete and an intimate knowledge of their influence generally and under particular conditions. Such knowledge can only be acquired by careful observation. The defects which these agencies may produce assume several forms. The channel may have too sharp a bend, which is destructive of the stability of its banks and an obstacle to navigation. It may be too shallow in certain parts, in consequence of the wearing away of the banks and the silting up of its bed. It may be too wide in places—a condition that may cause the last-mentioned defect, by reducing the velocity of the stream, and thereby favouring the silting up of the bed and the formation of shoals. It may even be too narrow in particular places, offering a high velocity at all times, and a tendency to flood in rainy seasons; or its declivity may be too flat in consequence of its too circuitous course, or the existence of obstacles to the flow of the current, such as islands, shoals, weirs, ill-designed bridges, and similar obstructions. Before any alteration in the bed of a river is attempted, the effect of such an alteration upon the current, both above and below that point, must be carefully considered. If the engineer neglect this precaution, he may find that he has produced a greater evil than he undertook to remove. As an example of an ill-considered measure, we may mention the case of the Robine, a canal running from the Aude to the Mediterranean through Narbonne, in France. The original constructors of this canal gave it a very circuitous course near this town for the purpose of increasing the depth by diminishing the velocity of the stream. Towards the end of the last century, the sinuosities being attributed to caprice, it was resolved to straighten the channel to expedite the navigation. When the work was completed, the draught of water was found to be insufficient.

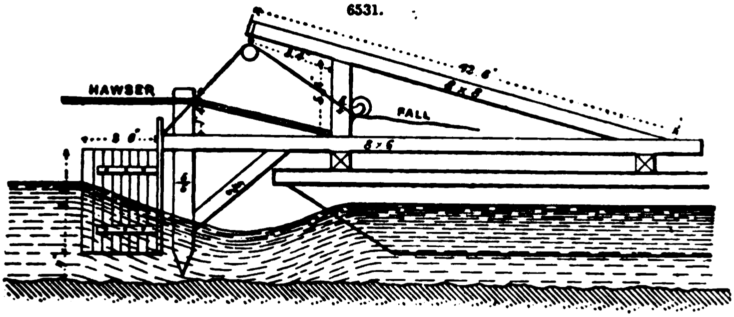
The object in all river improvements is to obtain a channel as near as practicable uniform in section, or gradually increasing from the source to the mouth, having sufficient capacity to carry off flood-water without overflowing, with a velocity that shall not endanger the stability of the banks. Thus it will be seen that the engineering works for the improvement of the upper portion of a river will consist chiefly of excavations to remove shoals and other obstructions, and to widen narrow parts, regulating dykes to contract wide shallows, diversions of the channel, and works for stopping useless branches.

The work of excavating the bed of a river for the purpose of deepening its channel consists mainly of dredging. This operation may be performed by hand, by steam, or by means of the current itself. When performed by hand, an implement called a spoon is employed. It consists of a pole, having at one end an iron ring steeled on the forward edge, to which a leathern bag is attached. The end of the pole is held by a man, and the ring is hung by rope tackle capable of being wound up by means of a crab. The man who holds the pole directs the forward edge of the ring against the bottom while the spoon is being dragged along by the winding up of the rope. When the spoon arrives beneath the crab, it is hauled up and its contents emptied into a barge. In cases where the depth of the water does not exceed 6 ft., this system of dredging may be employed with advantage, as it is both effective and cheap, it having been ascertained that the labour and cost of the operation are not much greater than in similar excavations on dry land. When, however, the depth is great, recourse must be had to the dredging machine. With a steam dredging machine, the cost of excavating is about the same as that of similar operations on dry land. A steam dredger of 16 horse-power will, under favourable circumstances, raise about 100 cub. yds. an hour.

The most economical means of removing the materials of the bed of a river when they consist of mud, sand, or light gravel, is the employment of the current for that purpose. The operation is performed by means of a kind of movable dam, usually consisting of a framework covered with boards attached to a boat. The boat is moored in the stream, and the dam lowered to within a few

inches of the bottom. The water-way being thus greatly contracted, the velocity of the current over the bed is proportionately increased, and this increased velocity will scour the bed to a considerable depth in a short time. From 30 to 70 cub. yds. may be excavated in this way by one boat. Fig. 6531 shows one of these dredgers as used on the Garonne, in which river it removed about 60 cub.

6531.



yds. a day of sand and clay, at a cost of about 2½*d.* a yard. It must be borne in mind that this mode of dredging acts only by displacing the materials of the bed, leaving them free to be deposited elsewhere. It cannot therefore be applied where a necessity exists for the removal of the materials disturbed.

When the bed is composed of rock, recourse must be had to blasting. If the current is low, it will often be advantageous to enclose such parts by temporary dams, as is done in the case of foundations, and to lay them dry.

When the shallowness of a river is caused by excessive width, the defect may be remedied by a regulating dyke or longitudinal embankment. These dykes may be constructed either of dry stone or of wattled piles and gravel. When built of stone, they should have a slope of about 1 to 1. The latter mode of construction is, however, the more usual. In this case the piles should have a diameter of not less than one-twentieth of the length; they should be driven into the ground in a double row to a depth equal to twice that of the water; the distance between the rows should be once and a half the depth of the water, and the distance of the piles apart, longitudinally, should be equal to the depth of the water. After being tied together transversely, the rows of piles are wattled with willow twigs, and the space between filled up with gravel. The various modes of executing the wattling will be described later.

The construction of dykes not only increases the depth by forcing the water to flow through a narrower channel, but the velocity of the water being thereby increased, the bed is scoured out until a sufficient depth is reached to establish equilibrium between the current and the materials of which the bed is composed. This consequence of erecting a dyke must be carefully calculated beforehand, and the amount of contraction duly apportioned to the results. It may be remarked here that the only certain means of permanently deepening the bed of a river is the construction of continuous longitudinal embankments. Dykes built in the same way as those described above are used to stop up side branches. In this case, they are thrown across the upper end of the stream from bank to bank. The effect of stopping up a branch is to throw a larger body of water into the main channel, the stream in which will be both deepened and accelerated thereby. Thus the consequences will be the same as those produced by the longitudinal dyke, and they will have to be calculated in the same way.

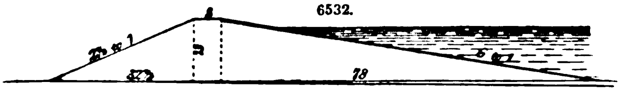
When the course of a river is so circuitous that the velocity of the current is not sufficient to prevent deposits, the bed silts up and the channel becomes too small to contain flood-water. Hence result disastrous inundations; and as each successive overflow carries away some of the bank, the evil tends to become worse. Moreover, as the low velocity in one part checks the flow of the stream higher up, inundations may result in other places. In such cases, it may be desirable to divert the stream into a new and straighter channel, excavated for it. Great caution is, however, necessary in undertaking a work of this nature. We have already directed attention to one of the effects of a cut-off in the case of the canal at Narbonne. More disastrous effects than the one referred to may be produced by the diversion of a stream. It must be borne in mind that a cut-off brings down the water from above it with a greater velocity than it possessed in its former sinuous channel. This is the object for which the cut-off was made, and the immediate effect of the increased velocity is to relieve that portion of the river which is situate above it. But the water enters the lower portion of the river with a greater velocity than when it followed the more circuitous course; and consequently the level in that portion is raised to a degree corresponding to the depression in the upper portion. Thus it will be seen that the only effect of a cut-off is to relieve one part of the river at the expense of another. Whether such a remedy will be beneficial or otherwise will depend upon the nature and capacity of the channel below the cut-off, and these must be carefully ascertained and considered before undertaking the diversion of the stream. When, however, such a remedy seems desirable, there are certain important points to be kept in view in the execution of the work. A primary point is to make the new channel as deep as possible. We have shown that the tendency of a river is to widen rather than to deepen its channel, and this must be kept in view in excavating a cut-off. Another important condition is to connect the new channel with the old by a curve of a considerable radius. Unless this condition be fulfilled, the stream will either not enter at all, or if it enter, will not flow freely in the new channel. It is also an advantage to slightly curve the new channel, for the current will then keep

constantly against the concave bank; whereas, if the channel is straight, it will deviate from side to side, and thus tend to produce bends. The velocity, too, is somewhat checked by the curved channel, and this will generally be an advantage. The new channel must not be opened to receive the waters of the river until the down-stream end of the old one has been completely closed. For it has been found impracticable to divert the stream into the new channel unless this be done, by reason of the impossibility of throwing out the new cut to a depth inferior to that of the old channel. It is also necessary to clear the bed of the new cut of all trees, reeds, or aquatic plants, as these impede the flow of the current and favour deposits.

The simplest and most effective means of protecting the adjacent land from inundation in consequence of a river overflowing its banks, is to increase, artificially, the height of the banks at those parts liable to overflow. This system of embanking rivers has been very extensively applied on the Continent and in America, and everywhere with the most complete success. Yet in England, notwithstanding the ravaging inundations which frequently occur, it is rarely resorted to. It may, however, be confidently expected that some effort will soon be made to prevent these oft-recurring floods, so discreditable to British engineering enterprise, and the value of the system, which is as inexpensive as it is efficacious, will force itself upon the notice of engineers. The mode of constructing these embankments differs but little in its main features from that adopted for embankments intended for other uses. Some of the details, however, require special mention; and we cannot give a clearer description of these than is contained in the following extracts from the specifications of the embankments constructed on the Mississippi, which specifications are sanctioned by the State.

"The embankment shall be graded 5 ft. wide on the top, except where otherwise directed by the chief engineer, with side slopes of 6 to 1 on the river side, and 2½ to 1 on the other side."

6532.



6533.

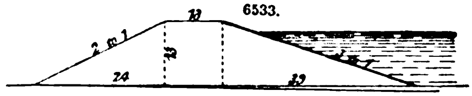


Fig. 6532 shows the profile of the embankment constructed according to this specification. The dimensions were, however, considered excessive by the engineers who conducted the survey of the river between the years 1850 and 1861, and in their report submitted to the Government in the latter year, they recommend that "the width at top shall be equal to the height, the outer slope 3 to 1 and the inner slope 2 to 1." This is more in accordance with the dimensions adopted in Europe. Fig. 6533 represents the profile as modified according to these recommendations.

"The ground to be occupied by the embankment must first be cleared of trees, stumps, roots, weeds, and all perishable matter, the trees and stumps being cut up by the roots, at least 1 ft. below the surface of the ground. The entire surface must then be thoroughly broken with a spade or plough, in order to form a bond with the earth deposited. Then a muck ditch must be cut, 6 ft. wide at top and 3 ft. at bottom, and 4 ft. deep; all stumps and roots crossing it being carefully taken out and removed beyond the base of the embankment. The muck ditch must be cut 10 ft. from the centre line of the embankment, great care being exercised not to displace any of the stakes of the centre line, on the side next the river, the earth from it being thrown entirely on that side of the ditch next the river. As each section of a mile in length is thus cleared, broken, and muck ditch cut, the contractor must notify the fact to the engineer in charge, when he will set stakes on each side of the centre at the proper distance for the base of the embankment. As soon as the work is staked, the muck ditch must be filled in again with buckshot-earth or clay, obtained from without the base of the embankment, and the earth tramped in by horses or mules ridden rapidly back and forward constantly while the earth is being put in; at least one horse to every eight wheelbarrows being thus employed. This filling and tramping to be kept one mile in advance of the embankment. In cases where the chief constituent of the embankment is sand or other porous material, the engineer may require a wall of buckshot or clay, 5 ft. thick, to be continued up from the muck ditch to the top of the embankment, the earth being tramped in by horses in the same manner as the muck ditch, as the embankment is built up on each side of it, the object being to obtain a stratum through the embankment impervious to water.

"When the ground is prepared in the manner set forth above, the embankment will be commenced, and it must be formed in uniform layers not exceeding 1 ft. in thickness; a sufficient number of men being continually kept on the embankment to spread the earth as it is wheeled or carted in. The slopes shall in every case be commenced *full out to the side stakes*, and carried regularly up as the embankment progresses.

"All earth designed for embankment must be *entirely* divested of roots and all other perishable matter. When the embankment has been raised 3 ft. the sides must be trimmed with slope-boards, and any irregularities appearing on the slope must be corrected at once; this trimming must steadily progress as the embankment increases in height.

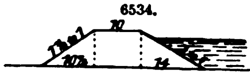
"The engineer may, whenever he deems it necessary, require a double course of sheet piling, breaking joints, to be driven at the centre or either side of the embankment, 5 ft. below the surface of the ground, and extending up within 6 in. of grade. All piling must be driven in advance of the embankment, which shall be constructed on both sides of the piling simultaneously. The ends of embankments shall be protected from flood by a double row of sheet-piling closely driven and securely braced, extending across the base and around each side, not less than 100 ft."

The cost of excavating embankments in accordance with the foregoing specifications is in the State of Mississippi from 18 to 20 cents the cubic yard.

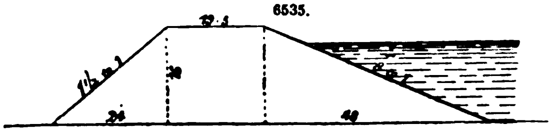
The French dykes on the Rhine, Fig. 6534, in that part of its course lying between the Black Forest and the Vosges mountains, where the height is 7 ft., have a width of 10 ft., the slope towards the river being 2 to 1, and towards the land 1½ to 1. When the height exceeds 7 ft., the width is increased by a banquette on each side.

The dykes of the Rhine in Holland, Fig. 6535, when near the river bank and when used for the road, have a width of 20 ft. on the top when 16 ft. high, a slope of 3 to 1 on the river side, and a slope of 1½ to 1 on the land side. The outer slope, when exposed to running ice, is protected by a revetment of brick or fascines. When the dyke is not near the river bank and is not used as a road, the width is only 6½ ft.

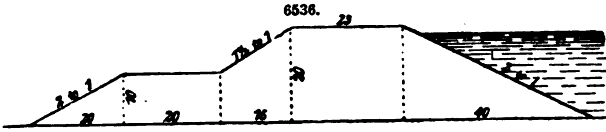
6534.



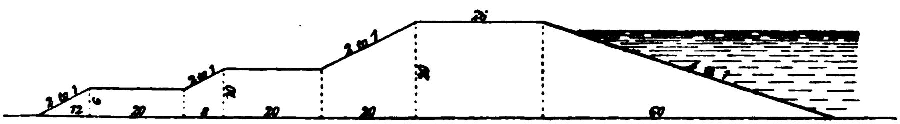
6535.



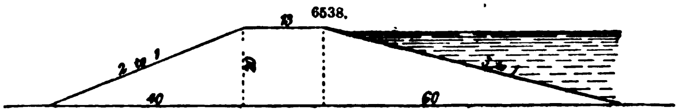
6536.



6537.



6538.

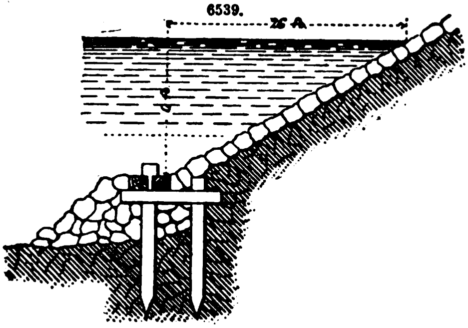


The dykes on the Po are 2½ ft. above the highest flood mark, their width is usually equal to the height, and the slope of their sides 2 to 1. When the soil is permeable, they are reinforced, Fig. 6536, at the height of the mean floods, by a banquette 20 ft. wide when the height is 20 ft. or upwards. Where the soil is very sandy and has but little cohesion, the dykes of the Po, when 20 ft. high and upwards, have a width at top of 26 ft., two banquettes 20 ft. broad, Fig. 6537, an outside slope of 3 to 1 and an inside slope of 2 to 1. The river roads are usually upon the embankment or upon the banquette.

The average height of the dykes on the Vistula, Fig. 6538, is 20 ft. The top is from 2 to 3 ft. above the highest flood. The width at top is usually 15 ft., or three-fourths the height, and the slopes are 3 to 1 and 2 to 1.

The protection of the banks of a river against the wearing action of the currents has now to be considered. The most efficient protection is a thick growth of aquatic plants; but as these constitute a serious impediment to the flow of the stream, artificial protection must be substituted for them. The means employed are various, differing according to the nature of the soil and that of the materials most readily available. Where stone is abundant and the slope of the banks suitable, dry stone pitching forms a very effective protection. This system has been adopted on the Loire where the pitching is remarkable for the perfection of its execution and its comparatively slight thickness. The slopes in these cases are generally about 1½ to 1. The stones are roughly squared and laid by hand in courses. The thickness of the pitching is from 8 to 12 in. at the top, and increases in going down at the rate of 2 or 3 in. a yard. A bed of gravel is laid beneath, and the foundations requisite to keep them from slipping are formed by a simple excavation or trough dug in the earth below the level of the mean summer waters, and subsequently filled in with rough rubble masonry. Sometimes, however, it is necessary to drive a row of piles with longitudinal wales, as shown in Fig. 6539. In calculating the strength of these wales we have only to consider that the maximum pressure they have to resist is $\frac{w \times s}{l}$, w being the weight of the pitching, s the rise of slope, and l the length of slope, friction being neglected for the sake of security.

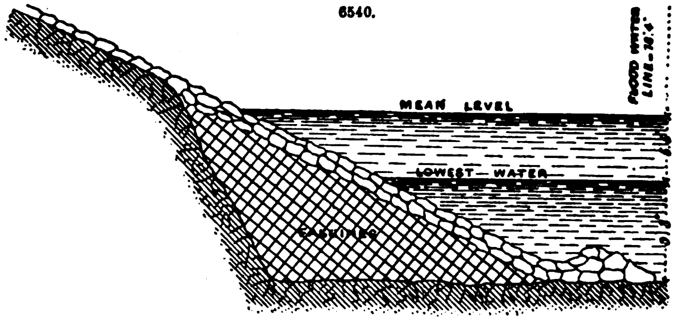
6539.



Where aquatic trees are abundant, fascines are employed instead of stone. These fascines are

bundles of willow twigs from 9 to 12 in. in diameter and about 12 ft. in length. They are laid with their length up and down the slope and are fixed to the bank by stakes. Sometimes a mixed system of fascines and stone pitching is adopted, as shown in Fig. 6540. Works executed in this way do

6540.



not, it is true, last very long, ten years being the limit of a fascine under water; but their duration is sufficient in rivers carrying much suspended matter, to give rise to depositions which eventually serve to effect the object intended in a more permanent way.

Timber sheeting is occasionally resorted to. This may consist either of sheet piling or of guide-piles and horizontal planks. The wales of the sheet piling or the guide-piles of the planking must be tied back to wooden anchoring plates firmly fixed in suitable situations. Sometimes it may be necessary to construct retaining walls to preserve the banks of a river; but such instances will seldom occur, and they will never extend beyond a very limited space. Groins are in some cases employed. These, however, should be used only as temporary expedients, as they impede the current and endanger the stability of the bed.

To render the upper portion of a river navigable, it is sometimes necessary to erect weirs in those portions of the stream which are naturally shallow and rapid. The object in this case is to produce a long reach of deep and comparatively still water. More frequently weirs are erected for purposes of water-supply or water-power. In the latter cases, the object is to prolong a high water-level from its natural situation to some place where it is required to divert water from the stream for the purpose of driving machinery, or for other purposes. These weirs are merely dykes or dams thrown across the stream; usually they are constructed of stone, but in some cases, especially in America, timber is employed for that purpose.

The pressures upon a weir being the same as those upon an ordinary reservoir wall, its dimensions are calculated in the same way. But as the water flows over a weir, forming a cascade on the down-stream side capable of undermining the base of the structure, a somewhat different mode of construction must be adopted, In choosing the site for a weir, it is well to avoid a bend if possible; because the water on leaving the weir possesses a high velocity, and if a bend be situate immediately below the weir, the concave bank is rapidly worn away. The usual position for a weir is at right angles to the banks. Sometimes, however, in order to diminish the height of the back-water in times of flood, the crest is made longer than the breadth of the channel, and this is effected either by placing it obliquely across the channel, or by giving it a V shape in plan. As a protection to the banks, the ends of the crest should be made slightly higher than the middle; the cascade is by this means directed towards the middle of the channel. The breadth of the crest should not be less than 2 or 3 ft.

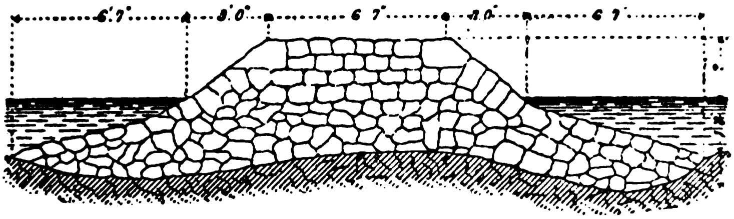
The up-stream face is either vertical or sloped to about 1 in 1. The down-stream face has usually a long flat slope varying from 3 to 1 to 5 to 1. This slope is for further protection continued a short distance below the bed of the channel. Another method is to form the down-stream face into a series of steps, so as to break the cascade into a number of smaller ones. Occasionally a vertical face is adopted, with a nearly level stone-pitching beneath; this form is, however, not suitable for large bodies of water.

Weirs may be constructed of any of the materials used for dams, and the principles of construction are identical in the two cases. When solid masonry is used, the facing should be of block-in-course or ashlar; but the heart may be of rubble or concrete. The same precautions are needed as in the case of reservoir walls, to prevent the filtration of water round the ends or roots of the weir. When the material employed is dry stone, the mode of construction is the same as that of the embankments already described. The slope in such cases is steep at the back and long and gentle in front. To prevent the stones from slipping on their foundations, piles with horizontal wales may be used in the manner recommended for embankments. The accompanying figures are given as examples of stone river-dams. Fig. 6541 is a section of a dam on the Loire at Orleans; Fig. 6542 a section of a dam constructed by Telford on the Weaver; and Fig. 6543 is a section of a dam on the Carron, by Smeaton.

Works for the improvement of the tidal portion of a river consists mainly of the removal of obstructions to the tidal flow. These obstructions may be either natural or artificial. Those of the former kind consist of abrupt bends, shoals, contractions of the channel, and bars, the removal of which may be effected in any of the ways already described in reference to the river proper. In considering, however, beforehand the effect of any proposed change, we have, in the tidal portion, another agent to be taken into account, namely, the tide. When estimating the effect of certain changes in the river portion, the problem is simplified by the fact that the current flows constantly in one direction; but in the tidal portion we have the current flowing alternately in contrary

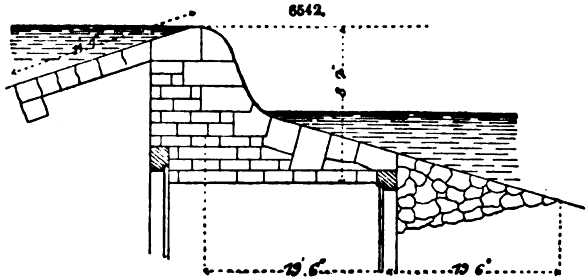
directions. Also in the former case we have to compute only the quantity of water passing down the channel; while in the latter it is necessary to ascertain not only the quantity of water brought

6541.

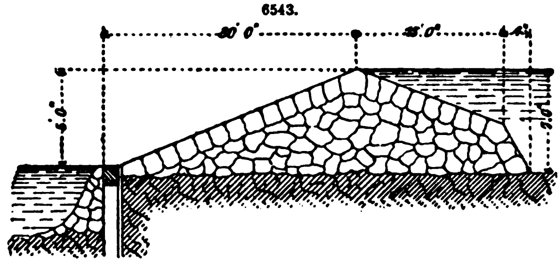


down, but also the quantity that ascends. These, however, are questions which may be determined by means of the hydrometrical observations already described. Beyond this the execution of the work will differ but little from that applicable to the former case.

6542.



6543.



The scouring action of the current forms a particular feature in the tidal portion of a river. The alternate ebb and flow of the tides carries up and down the river channel large quantities of sedimentary matter, especially sand. This is deposited at slack water, to be taken up again when the flow has fairly set in, in the contrary direction. Thus the form of the bed is constantly changing. Remarkable instances of this may frequently be seen in open estuaries filled with sand-banks. The upward flow of the current due to the rising tide excavates a channel through the sand forming the bed. This channel is a sinuous one in consequence of the tendency of the stream to deviate from one side to the other. The sinuosity thus begun is constantly being increased by the scouring action of the current on the concave side and the deposition of the sand on the other. Thus the course of the channel is being changed during the whole of the flow. If the current continued in the same direction, the sinuosities would increase until they extended from bank to bank, when they would become to a certain extent permanent. But in a few hours the tide recedes, and the current sets in the contrary direction. This current will not scour precisely as the ascending current did; the course of the channel will therefore be excavated in some other direction, in some cases it may even be scoured back into its first situation. In this way the course of the channel is constantly shifting, to the utter destruction of navigation. The only effective remedy for this appears to be the erection of training walls. These are longitudinal dykes, similar to those we have described for contracting the bed of the river proper. Their use is to confine the current, that is, the low-water stream, to a certain portion of the bed where it may constantly exert its scouring action upon the same line of channel. It is obvious that by this means a greater permanent depth may be obtained than by allowing the stream to continue its previous ever-changing course.

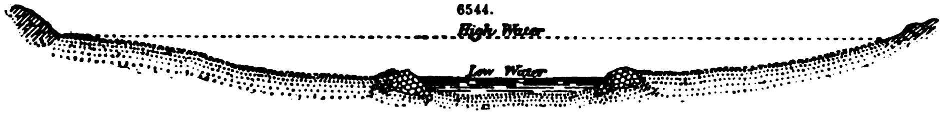
Training walls are constructed of rough rubble stones, backed with clay and gravel. Their distance apart must be determined by the fresh water and the tidal discharge, and the requirements of the navigation. In some instances the distance is from 400 to 500 ft. They should not be raised far above the low-water line; from 3 to 5 ft. will be sufficient, as it is desirable to avoid contracting the high-water channel. It has been found that these walls do not sink more than 2 or 3 ft. into the sand of the bed, and that their foundations, being parallel to the current, are unaffected by the scour. Figs. 6544, 6545, are cross-sections of training walls constructed by D. Stevenson.

Improvements of the channel by dredging and other modes of excavation, cut-offs, and closing of subsidiary channels, are executed in the manner we have already described for the upper portion of the river.

Among the chief artificial obstructions to the tidal flow are groins or jetties, and piers of bridges. Jetties were formerly considered the most practicable and efficient means of confining the current to the middle of the channel; but experience has shown that their influence is rather pernicious than otherwise. They give rise to eddies and back-currents, and constitute a serious impediment to the flow of the stream. Hence their use has been almost entirely abandoned for this purpose. But as they exist in many estuaries, their removal will frequently constitute one of

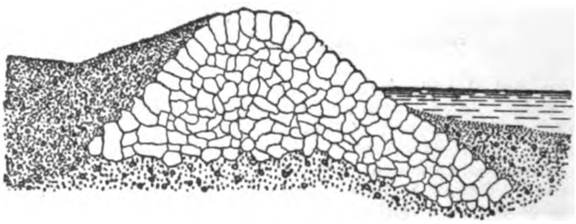
the first operations to be undertaken in the improvement of the tidal portion of a river. Piers of bridges offer considerable obstruction to the current. Of course, existing bridges can rarely be

6544.



removed; but when it does happen that an old bridge is to be rebuilt, or a new one erected, care should be taken to avoid, as much as possible, obstructing the water-way. A sharply-curved part of the channel should not be chosen as the site of the bridge, and, whenever practicable, the stream should be crossed at right angles. The abutments must not contract the water-way, and the piers should stand with their length exactly in the direction of the current. The piers should also have pointed or cylindrical cutwaters at both ends to diminish the obstruction they offer to the current.

6545.



One of the greatest difficulties which the hydraulic engineer has to deal with in the tidal portion of a river is the existence of bars. A bar is a bank of sand, gravel, or earth, forming a shoal at the mouth of a river, obstructing entrance or rendering it difficult. The depth upon the bar is, of course, the ruling depth of the channel, and it is frequently such as to allow the passage of large vessels only at high water. Bars exist at the mouths of nearly all tidal rivers, and various theories have been propounded concerning their formation. The most reasonable is that they are the work of the sea alone. A well-known action of the sea is to throw up upon the coast a girdle of sand or shingle. This action goes on at the mouths of rivers as elsewhere. It is, however, opposed by the down current of the stream; were it not so opposed, the sea would speedily close up the mouth of the river. The force of the sea waves, especially against the bottom, is greater than the opposing force of the stream; hence a bar is formed. But as the height of the bar increases, the forces become more equal, until finally, when equality has been established, the height becomes permanent. This permanent height of the bar may be temporarily diminished by storms and floods; but on the cessation of the disturbing cause, it will be soon restored. There are a few rivers that are not encumbered with bars, and their non-formation in these cases may be attributed to the absence of one or more of the following conditions laid down by a writer in the Encyclopædia Britannica as necessary to their formation;—1st. The presence of sand or shingle, or other easily-moved material; 2nd. Water of a depth so limited that the waves during storms may act on the bottom; and 3rd. Such an exposure as shall allow of waves being generated of sufficient size to operate on the submerged materials.

It will be seen from the foregoing remarks that as the bar is due to the action of the waves, so the depth of water over the bar is due to the scouring action of the current. Therefore, in all works intended for the improvement of the tidal portion of a river, the scour upon the bar must be kept in view. This scour is produced in a greater measure by the tidal than by the fresh water; for the volume of tidal water discharged over the bar is generally far greater than that of the water brought down by the stream. The question of back-water is thus a very important one. By back-water is meant the tidal water which at every tide flows over the bar, and which, with the fall of the tide, flows *back* to the sea. The quantity of back-water is obviously measured by the extent of the area above the bar over which it flows, and an important question for the engineer is how far this area occupied by back-water may be encroached upon by solid works displacing the water, without injuriously affecting the scouring force on the bar. At first sight it may seem that any diminishing of this area must lessen the scour. This, however, is not strictly true. Experience has shown that where certain physical conditions exist, the area occupied by back-water may be reduced without injuriously affecting its scouring action. It cannot be denied that engineers are not agreed on this matter; but the commonly-accepted opinion, founded on the limited experience available, is expressed in the following propositions advanced by D. Stevenson in his work on Inland Navigation;—

1. The depth on bars is due to back-water.
2. Where the high-water level of the surface of the river, estuary, or basin, is the same as, or higher than, the level seaward of the point of abstraction, a diminution of tide-covered area will reduce the effective back-water.
3. Where the high-water level of the surface of the river, estuary, or basin is lower than the level seaward of the point of abstraction, a diminution of tide-covered area may, in some cases, be made without reducing the effective back-water.
4. The lower the level of back-water, the greater will be its effect in scouring the low-water channel; and therefore the nearer the site of abstraction is to high-water mark, the less injurious will be the effect.
5. By enlarging the tidal capacity of a river at a low level, where the acquired volume is filled every tide, compensation may be given for a much larger amount of water excluded at a higher level.
6. In consequence of the disturbing effects of the waves of the sea, the large discharge of rivers

during high floods, and the varying nature of the beds of estuaries and bars, it is not possible to conclude that with a given quantity of back-water, as deduced from the measurement of the tidal capacity of an estuary, a constant navigable depth can be maintained over the bar.

In this, as in most other questions concerning alterations made in river channels, so much depends upon physical features peculiar to the locality, that every new case requires special observations, and the engineer is to a great extent thrown back upon his own resources. The foregoing propositions will, however, serve to direct his observations, and so enable him to arrive at results in which he may feel some degree of confidence.

See CANAL. DAMMING. LOCKS AND LOCK-GATES. RETAINING WALLS.

Books on Rivers;—Bernoulli (D.), 'Hydrodynamica,' 4to, 1738. Bernard (M.), 'Nouveaux principes d'Hydraulique,' 4to, 1787. Fabre (M.), 'La Théorie des Torrents et des Rivières,' 4to, 1797. Du Buat, 'Principes d'Hydraulique,' 3 vols. 8vo, Paris, 1816. Robison's (J.) 'Mechanical Philosophy,' 4 vols. 8vo, 1822. Brooks (W. A.), 'On the Improvement of Rivers,' 8vo, 1841. Minard (C. J.), 'Cours de construction des ouvrages qui établissent la Navigation des Rivières et des Canaux,' 4to, Paris, 1841. Calver (E. K.), 'Conservation and Improvement of Tidal Rivers,' 8vo, 1853. Ellet (C.), 'On the Mississippi and Ohio Rivers,' royal 8vo, Philadelphia, 1861. Neville (J.), 'Hydraulic Tables,' 8vo, 1861. 'Report upon the Physics and Hydraulics of the Mississippi River,' by Capt. Humphreys and Lieut. Abbot, royal 4to, Philadelphia, 1861. Beardmore (N.), 'Manual of Hydrology,' 8vo, 1862. Frisi, 'Treatise on Rivers and Torrents,' translated by Major Garstin, 12mo, 1868. Stevenson (D.), 'The Principles and Practice of Canal and River Engineering,' royal 8vo, 1872. 'Great Rivers; the Parana, the Uruguay, and the La Plata Estuary,' by J. J. Révy, folio, 1873. Hewson (W.), 'Principles and Practice of Embanking Lands from River Floods,' 8vo.

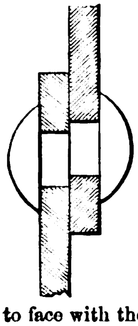
RIVETED JOINT. FR., *Rivure;* GER., *Vernietung;* ITAL., *Commessura ribadita;* SPAN., *Junta de roblones.*

Riveting, or the art of forming a *riveted joint*, has become one of the most important in mechanical engineering, as in boiler work, girder work, iron shipbuilding, and in wrought-iron work generally, it constitutes an essential and a principal feature. The best form of riveted joint and the most suitable and economical proportions of the several parts of which it is composed are therefore problems deserving the most careful attention. It is strange that so important a matter should have been so little investigated; yet it is a fact that few experiments worthy of the name have been made to discover the principles according to which a joint ought to be designed, and the rules of practice have been left almost wholly to empirics. The consequence is that in our investigations of this subject we must rely chiefly upon theoretical considerations, guided, however, by the results of the few authenticated experiments which have been carried out.

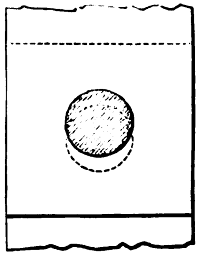
The question is, given two iron plates that are to be joined along two edges, how is this joint to be made in the strongest and at the same time the most economical manner. Obviously the only way of effecting the join in a perfect manner is to weld the two edges; and accordingly many attempts have been made to execute the joint in this way. There are, however, so many practical difficulties to be encountered, that little is to be hoped for in this direction, in the case of long joints at least. Riveting must therefore continue to hold its present important position. There are two ways of forming a riveted joint. One is to make the two edges overlap each other, and then to pass a pin or bolt through holes opposite each other in the overlapping parts. This is known as the lap-joint, and is the simplest mode of joining two plates. The other way is to place the two edges flush with each other, and to connect them by means of a strip, overlapping both, and riveted as in the former case. This is called the butt-joint. It is obvious that this joint is nothing but the lap-joint repeated, as the strip may be considered as a third plate to which the other is joined. It possesses, however, certain advantages, one of which is that it may be used on both sides of the plates. The reality of this advantage will be seen later.

Now it is evident that a joint executed in this manner can never be so strong as the plate itself, because a portion of the plate has to be cut away to admit the rivets. The effective area of the plate is thus reduced by a quantity equal to the sum of the areas of the rivet-holes. This does not quite represent the reduction of strength, because the plate which is left between the holes is, in some way not yet clearly ascertained, injured by the operation of forming the holes. But for the present we will assume that it does not accurately represent the loss of strength. In practice this loss is a serious one, amounting to 50 and even 60 per cent. of the strength of the plate. Thus, in the case of a boiler, for example, one-half the metal is wasted. The remedy that first suggests itself is to use as few rivets as possible, and to give those the least possible diameter. But here we come

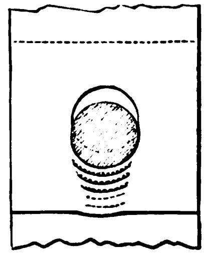
6546.



6547.



6548.

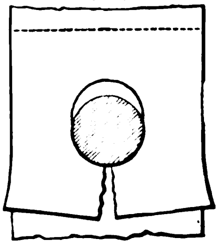


face to face with the manner in which a riveted joint yields. A joint of this kind may give way; 1, by the shearing of the rivet, as in Figs. 6546, 6547; 2, by the crushing of the plate, Fig. 6548;

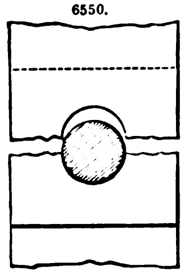
3, by the tearing out of the rivet, in Fig. 6549; and by the tearing of the plate across, Fig. 6550. Another mode of fracture, namely, that represented in Fig. 6551, is considered by some to be the normal manner in which a rivet forces its way out of a plate. This manner, it will be seen, is by shearing the plate. There does not, however, appear to be any reason for believing that such an action may occur; nor is it compatible with the modes of fracture shown in Figs. 6549, 6550. The resistance of the joint to fracture by the shearing of the rivet is—

The shearing strength the square inch × the sectional area of the rivet.

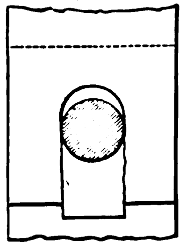
6549.



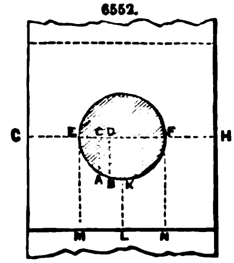
6550.



6551.



6552.



Here one means of reducing the area abstracted from the plate for the holes at once suggests itself, namely, the employment of the best quality iron for the rivets. In the case of the crushing of the plate, the resistance offered by any portion A B of the circumference, Fig. 6552, to the tensile strain, equals its resolved portion C D at right angles to the line of strain, multiplied by the thickness of the plate and by its crushing strength. Hence the resistance offered by the plate to crushing equals

The crushing strength × the thickness of plate × the diameter of rivet.

In the case of the joint failing by the plate breaking along the line K L, Fig. 6552, the portion E M N F opposed to the rivet may be considered as a continuous girder uniformly loaded, and the ultimate resistance then equals

$$\frac{\text{thickness of plate} \times (\text{depth K L})^2}{\text{length E F}} \times A,$$

A being a constant, the value of which must be determined by experiment, as the circumstances differ widely from those of ordinary girders. This mode of fracture is given by Walter R. Browne in a valuable paper read by him before the Institution of Mechanical Engineers, to which paper we are indebted for the accompanying diagrams. But it is a case of little importance in practice. There are but three modes practically by which a riveted joint may fail, namely, the shearing of the rivets, the crushing of the plate, and the tearing of the plate along the line of rivets. The resistance to this mode of fracture equals

The effective sectional area along that line × the tensile strength the square inch.

Thus it will be seen that fracture by shearing depends on the diameter of the rivet; that fracture by crushing depends on the diameter of the rivet and the thickness of the plate; and that fracture by tearing depends on the thickness of the plate and the width on each side of the rivet. Now it is sufficiently obvious that in a perfect joint these several resistances will be equal to each other and the greatest possible; for whatever excess we have in one mode of resistance must be abstracted from another mode of resistance. If we increase the number of rivets, we increase the resistance to shearing, but we diminish the area of the plate along the line of rivets. If we diminish the number of rivets, we increase the strength of the plate, but we diminish the resistance to shearing. Again, if we diminish the number of rivets and increase their diameter, we increase, indeed, both the resistance to shearing and to tearing, but we diminish the resistance to crushing. Thus we have found a certain definite point at which to aim in designing a riveted joint, namely, equality of resistance. By comparing the first and second modes of fracture, we obtain the proper proportion between the diameter of the rivet and the thickness of the plate; and by comparing the first and last modes of fracture, we obtain the pitch of the rivets, or their distance apart.

To compare the first and second modes of fracture, let t be the thickness of the plate and d the diameter of the rivet. Putting P = the strain a square inch that will crush the plate, and P' the strain a square inch that will shear the rivet, we have $\cdot 7854\, d^2 P' = P\, t\, d$, whence $\frac{d}{t} = \frac{P}{\cdot 7854\, P'}$, which is the requisite proportion between the diameter of the rivet and the thickness of the plate.

The shearing strength P' of wrought iron is usually taken as equal to its tensile strength. W. R. Browne, however, considers the tensile strength of riveted plates as somewhat inferior to their shearing strength, and he cites in support of his opinion numerous experiments made by independent authorities. The results of these experiments lead him to conclude that with the best quality iron, such as is used for rivets, the shearing strength should be taken equal to 22 tons the square inch, and the tensile strength of the plates 18 tons the square inch. The value of P, or the resistance to crushing, has not been determined with much precision. We should be far from the truth if we were to take the ordinary values for the crushing strength of wrought iron. The actual value of P is much higher than this, and the reason given by Browne is that experiments for values of crushing strength are made with cubes or short bars of the metal, which are free to move laterally in all directions; but in the case of a rivet-hole, the metal that is being crushed, or, as he expresses it,

crippled, is supported both by the surrounding part of the plate and also by the heads of the rivet. As this writer appears to have been the first to make direct experiments for the purpose of determining the value of P in riveted plates, we shall give his own account of them, and accept the value he has arrived at. After alluding to certain experiments made by Charles Fox, and others, on suspension-bridge links, he says;—

"As however in these sets of experiments a single pin with links of best bar iron was employed, it seems very desirable for the present object to make some further experiments with actual boiler plates and rivets; and for this purpose a series of plates were prepared, and tested at Kirkaldy's works. In order to make sure that the joints should yield by this mode of fracture and no other, the rivets were made altogether out of proportion to the thickness of the plates, which was $\frac{5}{16}$ in., while the rivets were 1 in. diameter; ample width was also given to the lap. The width of the joint in the line of the rivets was 13 in., and three rivets were employed in all cases. Half the specimens experimented upon were made with a lap-joint, and the other half with a butt-joint and two cover-plates; the pitch of the rivets was 3 in. in the lap-joints, and $3\frac{1}{4}$ in. in the butt-joints.

"On the plates being tested by tension in Kirkaldy's machine, they all without exception tore through the rivet-holes, as in Fig. 6550. But the tensile strength per square inch of the area fractured was greatly below the strength of the plates, being only an average of 12·2 tons in the lap-joints and 13·2 tons in the butt-joints; and it follows therefore that the joints could not have yielded by fair tearing of the plates. The crippling action at the rivet-holes, which is now being inquired into, would injure and weaken the metal, until either the rivets forced themselves out of the plate, or the plate itself tore through the holes. The latter happened first in these experiments; but there is no reasonable ground for doubting that the ultimate cause of failure was the crippling of the metal in front of the rivets.

"In order to test the reality of this crippling action, similar specimens of all the three qualities of iron that had been used, and of both kinds of joint, were subjected to a total tensile strain of 36 tons on the 13 in. width, and the rivet-heads were afterwards planed off, so as to examine the dimensions of the holes. A slight but unmistakable elongation was found to exist in the direction of the strain, amounting to about $\frac{1}{50}$ in.; and taking into consideration that this is of the character of a set, and also bearing in mind the way in which the metal is grasped by the rivet-heads, and the support given by the surrounding plate, the amount of elongation appears quite sufficient to prove the existence of the crippling action. At the same time the ultimate tearing of the plates at the rivet-holes serves to show why this crippling has attracted so little notice; and that, when not carried so far as to result in tearing, it may still exist as a dangerous and unsuspected source of weakness in joints otherwise excellent.

"The mean value obtained from the experiments for the ultimate resistance to crippling of the plate, per square inch of the area of pressure in the rivet-holes, is 39·5 tons for the lap-joints, and 42·9 tons for the butt-joints. These show a very close agreement with the results previously obtained from the experiments with suspension-bridge links, which average 39·8 and 40·5 tons an inch. The resistance to crippling appears therefore to be very different from and independent of the tensile strength of the iron; and as a general result, 40 tons per inch may be taken as the strain that will cripple the plate, or the value for P in the calculation."

Substituting these values of P and P′ in the equation, we find the value of d to be $2\cdot3\,t$, or about $2\frac{1}{4}$ times the thickness of the plate. In practice it is usual to make $d = 2\,t$, or the diameter of the rivet equals twice the thickness of the plate. The ordinary rule may thus, in the absence of more numerous experiments, be taken as sufficiently accurate.

We have now to determine the pitch, or distance of the rivets apart from centre to centre, so as to equalize the shearing strength of the rivets and the tensile strength of the plate. This question involves certain disputed points, and, as might be supposed, practice shows an absence of uniformity in this matter. The strength of the plate is equal to that of its sectional area between the rivet-holes. But what this strength is has not yet been determined with sufficient precision to set the question at rest. Experiments have proved beyond all doubt that the net area of the plate along the line of rivets is considerably weaker than an equal area of solid plate. The cause of this weakening has been attributed to the destructive action of the punch; and the advocates of drilling have relied chiefly upon this point in estimating the merits of the latter system. On the other hand, it has been contended on the faith of certain experiments, that a punched joint is as strong as a drilled joint, and that consequently drilling is as injurious as punching. Whatever the cause may be, however, it is certain, as we stated above, that the tensile strength of the net area is reduced by the existence of the rivet-holes, whether they are drilled or punched; and the question that remains is, does punching reduce the strength in a greater degree than drilling? It follows also from this fact that it is erroneous to assume, as is constantly done in practice, that the net area between drilled holes is equal in tensile strength to that of the solid plate. The only experiments, of which we are aware, that have been systematically carried out for the purpose of determining these questions, were made in America, and reported by a committee on boilers and boiler materials, to the American Railway Master Mechanics' Association. The following are the particulars of these experiments;—

Description.	Experiment Number.	How Broken.	Breaking Strain, lbs.	Unit Strain on Plate, tons a square inch.	Unit Strain on Rivet, tons a square inch.
Entire plate, $1\frac{3}{4}$ in. by $\frac{5}{16}$ in.	1	Torn across .	32,228	26·3	..
	2	Ditto	32,228	26·3	..
	3	Ditto	33,600	27·4	..
		Mean ..	32,685	26·7	..

TABLE—*continued.*

Description.	Experiment Number.	How Broken.	Breaking Strain, lbs.	Unit Strain on Plate, tons a square inch.	Unit Strain on Rivet, tons a square inch.
Plate $1\frac{3}{4}$ in. by $\frac{5}{16}$ in.; with $\frac{5}{8}$-in. hole through middle, punched	1	Torn across .	13,371	17·0	..
	2	Ditto	13,371	17·0	..
	3	Ditto	13,714	17·4	..
		Mean ..	13,485	17·1	..
Plate $1\frac{3}{4}$ in. by $\frac{5}{16}$ in., with $\frac{5}{8}$-in. hole through middle, drilled	1	Torn across .	17,828	22·6	..
	2	Ditto	17,485	22·2	..
	3	Ditto	17,622	22·4	..
		Mean ..	17,645	22·4	..
Two plates, each $1\frac{3}{4}$ in. by $\frac{5}{16}$ in., punched, and riveted together with a $\frac{5}{8}$-in. rivet	1	Torn through centre of plate	17,828	22·6	25·9
	2	Ditto	17,828	22·6	25·9
	3	Ditto	17,143	21·8	24·9
		Mean ..	17,599	22·3	25·6
Two plates, each $1\frac{3}{4}$ in. by $\frac{5}{16}$ in., drilled, and riveted together with a $\frac{5}{8}$-in. rivet	1	Rivet sheared	17,143	21·8	24·9
	2	Ditto	16,457	20·9	23·9
	3	Ditto	15,428	19·6	22·4
		Mean ..	16,342	20·8	23·8

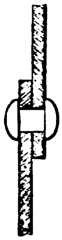
It will be remarked that the tensile strength of the plate experimented upon was very high. Beyond this, the Table contains some very remarkable results. The existence of the drilled hole reduced the tensile strength of the effective area from 26·7 to 22·4 tons the square inch, or about 16 per cent., while in the case of the punched hole the reduction was from 26·7 to 17·1 tons, or about 36 per cent. When, however, the rivet was inserted, the strength of the punched joint was about equal to that of the plate with the drilled hole, while the strength of the drilled joint was considerably less. The increase of strength in the punched joint can only be attributed to the grip of the rivet-heads, while the reduction of strength in the drilled joint is obviously due to an increased tendency to shear the rivet. This result is considered by the committee as probably due to the edges of the drilled holes being sharper and more compact, and consequently more capable of shearing than the edges left by a punch. However this may be, the fact remains that practically the drilled joints were not so strong as the punched joints. The result which bears directly upon the question we are now considering is that which relates to the diminished strength of the metal between the rivet-holes. This is shown to be 16 per cent. for the drilled hole, and 36 per cent. for the punched hole. We cannot help believing that the punching in this case must have been carelessly performed, and that 36 does not fairly represent the average punched hole. We have already said that W. R. Browne considers the tensile strength of a punched iron plate to be reduced from 22 to 18 tons, and he makes the latter strength the basis of his calculations. It is probable, however, that 17 tons more nearly represents the truth. The equation for determining the pitch evidently is $\cdot 7854\, d^2\, P' = 2\, b\, t\, R$, R being the resistance to tearing in tons to the square inch, and b the breadth required on each side of the hole. Putting $R = 17$, we have $b = 5 \times \frac{d}{t} \times \cdot d$; and taking $d = 2\,t$, $b = d$. That is, the breadth on each side of the rivet-hole should be equal to the diameter of the rivet; or in a row of rivets, the pitch should be equal to 3 diameters. When the diameter of the rivets is less than twice the thickness of the plate, as it must necessarily be in the case of very thick plates, the pitch will be less; and if m be taken as the ratio of the diameter to the thickness, the space between the holes will be m times the diameter of the rivet.

The distance of the rivet from the end of the plate, or as it is termed the lap of the plate, is made equal to one diameter. This distance has been determined more by practical necessity than from theoretical considerations; and as joints rarely, if ever, fail in that direction, it may be assumed to be sufficient. The loss of a single-riveted joint is thus equal to three diameters. The proportions to which the preceding considerations have led us are thus;—diameter of rivet = twice the thickness of the plate; pitch = three diameters of rivet; and lap = three diameters of rivet. These proportions are represented in Figs. 6553, 6554. The proportional strength of such a joint is evidently $\frac{2}{8}$ of $\frac{17}{22}$ or $51\frac{1}{2}$ per cent. of that of the solid plate.

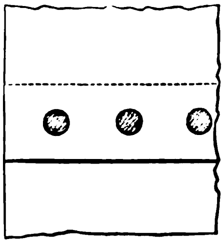
The foregoing conclusions show that the single-riveted lap-joint is only half as strong as the solid plate, even when most perfectly designed; and the question for consideration now is—by what change in the mode of construction can the strength of the lap-joint be increased. The first expedient that suggests itself is to place the rivets in two rows, since by this means we increase the pitch without reducing the sectional area of the rivets. This expedient has been largely resorted to, and the advantage which it offers is real and considerable. The pitch of the rivets in this case

will be double that requisite for single riveting, and our calculations showed us that in the latter case the pitch should equal three diameters. This, however, will not give the required equality between shearing and tensile strength. This equality is given by the equation $2\,(\cdot 7854\, d^2\, P') = 2\, b\, t\, R$. Whence, with the preceding values, $b = 2 \cdot 02\, d$, and the pitch consequently equals 5 diameters. But as the rivet-holes are wider apart, the tensile strength of the plate is reduced in a proportionably less degree. Browne takes $19\frac{1}{2}$ tons, instead of 17 as above, for the value of R in this case, which gives the pitch = $4\frac{1}{2}$ diameters. Thus we have increased the number of rivets and consequently the cost; but we have increased the strength of the joint from $\frac{2}{3}$ of $\frac{17}{22} = 51 \cdot 5$ per cent., to $\frac{3 \cdot 5}{4 \cdot 5}$ of $\frac{19 \cdot 5}{22} = 69$ per cent. The proportion of the diameter of the rivets to the thickness of the plate will be the same as in single-riveted joints, as the strains are the same in both cases.

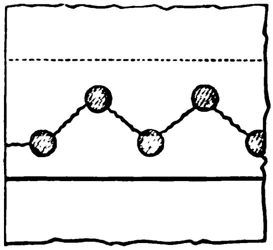
6553.



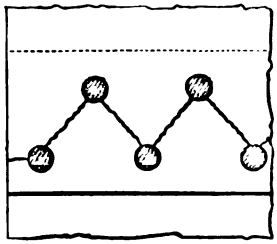
6554.



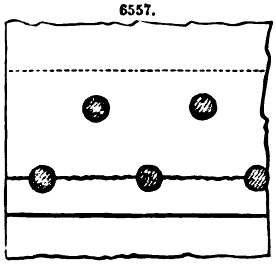
6555.



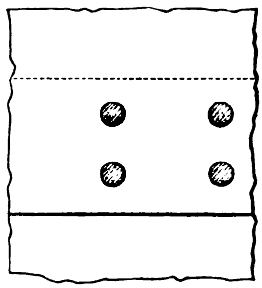
6556.



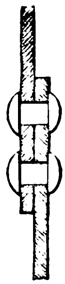
6557.



6558.



6559.



It now remains to determine the lap of the joint, and to do this it is necessary to ascertain what distance is required between the rows of rivets. Here again we find a want of uniformity in practice. The only experiments bearing directly on this matter are some made by Brunel, and described by W. R. Browne in the paper already referred to. Discussing the results of these experiments, he says, " In these the line of fracture in several cases was a zigzag, running backwards and forwards between the two rows of rivets, as in Figs. 6555, 6556; and this shows that the rows were too near together in those cases. As the effect of punching is to weaken the plate to some distance all round the punched hole, the result will be that in the space between any two successive holes in the straight line of rivets the plate is weakened to twice the distance that the punching affects, but in the zigzag line between the same two holes the plate is weakened to the extent of four times the same distance. Hence, though the zigzag line will always be the longer in itself, it may be really weaker than the straight line, if the two rows are near together. The proportion of the distance between the pitch lines to the pitch itself was respectively from 40 per cent. in Fig. 6555, to 62 per cent. in Fig. 6556, in the experiments in which the fracture took the zigzag line; but in another experiment, Fig. 6557, in which the proportion was as great as 67 per cent., the fracture took place in the straight line. It therefore seems safe to make the distance between the pitch lines 67 per cent., or $\frac{2}{3}$rds of the pitch in zigzag riveting.

" In chain-riveting, however, the rivets in the second row being opposite those in the first row, as in Figs. 6558, 6559, are in the same position with respect to the first row as the rivets in a single-riveted joint to the edge of the lap. Hence by the same rule as before, the distance between the rivet-holes in the two rows will be one diameter, making the distance between the pitch lines 2 diameters; but as the plate between the holes will be injured at both sides by punching, it will be safer to make the distance $2\frac{1}{2}$ diameters between the pitch lines. This gives the total lap $5\frac{1}{2}$ diameters in chain-riveted joints, which agrees with the rules in use at Lloyd's."

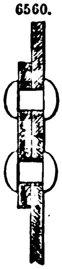
In considering the case of thick plates, as in marine boilers, where the diameter of the rivets cannot be made twice the thickness of the plate, the proportion of $1\frac{1}{2}$ times may first be taken; and substituting this value $d = 1\frac{1}{2}\, t$ in place of $d = 2\, t$ in the previous calculations, the results are Pitch = $3\frac{3}{4}$ diam., Strength $\frac{19 \cdot 5}{22 \cdot 0} \times \frac{2 \cdot 66}{3 \cdot 66} = 64$ per cent. Taking next the diameter of rivet equal to the thickness of plate, the corresponding results are

$$\text{Pitch} = 2\tfrac{3}{4} \text{ diam., Strength } \frac{19 \cdot 5}{22 \cdot 0} \times \frac{1 \cdot 75}{2 \cdot 75} = 56 \text{ per cent.}$$

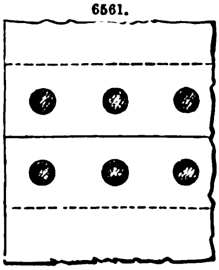
There is yet another mode of arranging the rivets, namely, in three rows; and the foregoing formulæ, when adapted to this case, give 4 diameters as the pitch of the middle row, and 8 diameters as the pitch of the outer rows. With these proportions, this triple riveting gives a strength of joint equal to 80 per cent. of the plates. We are soon stopped, however, in this direction by a practical difficulty, whenever a joint has to be made steam-tight. When the pitch is very wide, the plates are apt to spring under the calking tool. This difficulty of calking the joint has had great influence in checking the extension of the system of multiple riveting; and it is evident that further progress can be made only by effecting improvements in the methods of calking.

In butt-joints, a cover-strip is riveted to each plate, and this cover-strip may be placed on one side of the plates only, as in Figs. 6560, 6561, or on both sides, as in Figs. 6562, 6563. As we have previously said, when the cover is on one side only, the joint is virtually a lap-joint, and therefore the proportions found for this latter joint are equally applicable to the butt-joint. It is evident also that the butt-joint may be either single or double riveted, and it is equally evident that the thickness of the cover should be equal to that of the plates. If the cover-strips are double, the strain is equally divided between them, and therefore each strip should be half the thickness of the plate. In this case the rivets are in what is called double shear; that is, if they fail, they must do so by being sheared in two places. Consequently they offer a double shearing area, and hence the equation becomes $\cdot 7854\, d^2 \times 2\, P' = t\, d\, P$. The proportion of the diameter of the rivets to the thickness of the plate is thus $\frac{d}{t} = \frac{P}{1 \cdot 57\, P'}$. Whence we deduce $d = 1 \cdot 16\, t$, or the diameter of the rivet equal $\frac{1}{8}$ times the thickness of the plate. The equation for the pitch becomes $\cdot 7854\, d^2 \times 2\, P' = 2\, b\, t\, R$, from which we find pitch = $3\frac{1}{8}$ diameters. The proportions of lap will be the same as in the lap-joint, that is, there will be 3 diameters on each plate, making the total width of the covers equal to 6 diameters.

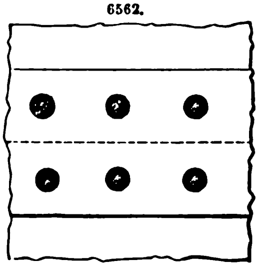
6560.



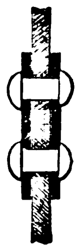
6561.



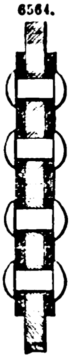
6562.



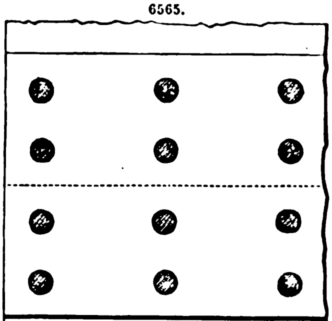
6563.



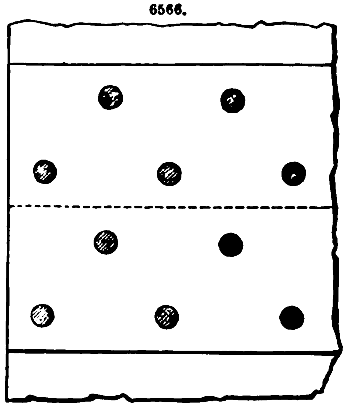
6564.



6565.



6566.



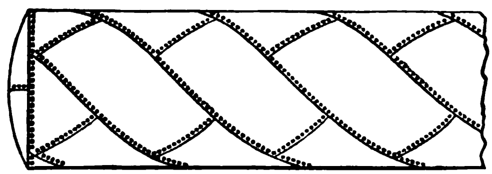
The proportionate strength of this joint, as compared with that of the solid plate, is $\frac{2\frac{1}{8}}{3\frac{1}{8}}$ of $\frac{17}{22} = 52\frac{1}{2}$ per cent.

When the cover-strips of a butt-joint are each double riveted, as in Figs. 6564 to 6566, the diameter of the rivets will be the same as in the single-riveted joints, namely, $1\frac{1}{8}$ the thickness of the plate; also, the distance between the two rows of rivets will be the same. Hence the width of the cover will be double the lap determined for the previous case, or for chain riveting, 11 diameters. The equation for the pitch is $2\,(\cdot 7854\, d^2 \times 2\, P') = 2\, b\, t\, R$, whence it will be found that the pitch $= 5\frac{1}{8}$ diameters; therefore, for zigzag riveting, the distance between the pitch lines being two-thirds of the pitch, we may take the width of the cover-strips as equal to 13 diameters.

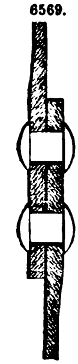
The proportionate strength of this joint, as compared with that of the solid plate, is $\frac{4\frac{1}{8}}{5\frac{1}{8}}$ of $\frac{19\frac{1}{2}}{22} = 71$ per cent.

Other expedients have been resorted to for strengthening the seams of boilers. In a boiler, the strain upon the longitudinal joints is twice that upon the transverse joints, and it has been proposed to arrange the joints diagonally, as in Fig. 6567. If the angle of the joint be 45°, a simple calculation will show that the tension upon it is only four-fifths of that upon a longitudinal joint. Consequently the effective strength of the joint is increased in the ratio of 4 to 5. This is an advantage which should not be overlooked. Another mode of making the strength of the transverse and longitudinal joints equal is to thicken the edges of the plates, as shown in Figs. 6568, 6569.

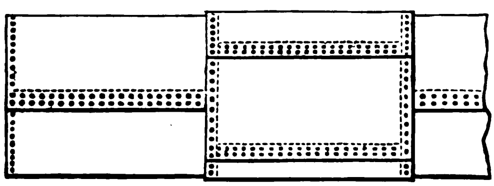
6567.



6569.



6568.



The following Tables show the proportions for riveted joints adopted in practice.

Rules for Boiler Riveting.

Thickness of Plate.	Diameter of Rivet.	Length of Rivet from Head.	Pitch.	Lap in Single Joints.	Lap in Double Joints.	Equivalent Length of Head.
inch.	inch.	inches.	inches.	inches.	inches.	inch.
$\frac{3}{16}$	$\frac{3}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$ to $1\frac{1}{2}$	$1\frac{1}{4}$	$2\frac{1}{16}$	$\frac{1}{2}$
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{2}$ „ $1\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$\frac{5}{8}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$ „ $1\frac{7}{8}$	$1\frac{7}{8}$	$3\frac{1}{8}$	$\frac{3}{4}$
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{7}{8}$ „ $2\frac{1}{4}$	$2\frac{1}{4}$	$3\frac{3}{8}$	$\frac{7}{8}$
$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{1}{4}$	$2\frac{1}{8}$ „ $2\frac{3}{8}$	$2\frac{3}{8}$	$3\frac{3}{4}$	$1\frac{1}{8}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$ „ $2\frac{1}{2}$	$2\frac{1}{2}$	$4\frac{1}{8}$	$1\frac{3}{8}$
$\frac{5}{8}$	$\frac{15}{16}$	$2\frac{3}{4}$	$2\frac{1}{2}$ „ $2\frac{3}{4}$	$2\frac{3}{4}$	$4\frac{3}{8}$	$1\frac{1}{2}$
$\frac{11}{16}$	1	3	$2\frac{3}{4}$ „ 3	3	5	$1\frac{5}{8}$
$\frac{3}{4}$	$1\frac{1}{8}$	$3\frac{1}{4}$	3 „ $3\frac{1}{4}$	$3\frac{1}{4}$	$5\frac{7}{8}$	$1\frac{3}{4}$

Lloyd's Rules for Ship Riveting.

Thickness of plates in inches	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$	$\frac{16}{16}$	Rivets to be $\frac{1}{8}$ of an inch larger in diameter in the stem, stern-post and keel.
Diameter of rivets in inches	$\frac{5}{8}$			$\frac{3}{4}$			$\frac{7}{8}$			1			

"The rivets not to be nearer to the butts or edges of the plating, lining-pieces to butts, or of any angle-iron, than a space not less than their own diameter, and not to be farther apart from each other than four times their diameter, or nearer than three times their diameter, and to be spaced through the frames and outside plating; and in reversed angle-iron, a distance equal to eight times their diameter apart. The overlaps of plating, where double riveting is required, not to be less than five and a half times the diameter of the rivets; and where single riveting is admitted, to be not less in breadth than three and a quarter times the diameter of the rivets."

Liverpool Rules for Ship Riveting.

Thickness of plate in inches		$\frac{5}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$	$\frac{16}{16}$
Diameter of rivets in inches		$\frac{9}{16}$	$\frac{10}{16}$	$\frac{10}{16}$	$\frac{12}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{14}{16}$	$\frac{15}{16}$	$\frac{16}{16}$	$\frac{17}{16}$	$\frac{18}{16}$
Breadth of lap in seams in inches ..	Single riveting	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$	..	..	..	..	..	..	..	..
	Double riveting	3	$3\frac{3}{8}$	$3\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{7}{8}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{5}{8}$	6	$6\frac{3}{8}$	$6\frac{3}{4}$
Breadth of butt-strip ..	Double riveting	$7\frac{1}{4}$	8	8	10	10	$10\frac{3}{4}$	$11\frac{1}{2}$	$11\frac{1}{2}$	$12\frac{1}{4}$	13	$13\frac{3}{4}$	$14\frac{1}{2}$
	Treble riveting	9	$11\frac{1}{2}$	$11\frac{1}{2}$	$13\frac{1}{2}$	$13\frac{1}{2}$	15	16	16	17	18	19	20

"Rivets to be 4 diameters apart from centre to centre, longitudinally in seams, and vertically in butts, except in the butts where treble riveting is required, where the rivets in the row farthest from the butt may be spaced 8 diameters apart from centre to centre. Rivets in framing to be eight times their diameter apart from centre to centre, and to be of the size required in the preceding Table. All double or treble riveting in butts of plates to be in parallel rows, or what is termed chain riveting. It is recommended that the necks of all rivets be bevelled under the head, so as to fill the countersink made in punching, and their heads should be no thicker than two-thirds of the diameter of the rivet."

See BOILER. CORROSION. MATERIALS OF CONSTRUCTION.

Works relating to Riveting;—Stoney (B. B.), 'Theory of Strains,' 8vo, 1873. Burgh (N. P.), 'A Treatise on Boilers and Boiler Making,' 4to, 1873. Fairbairn (Wm.), 'Useful Information for Engineers.'

ROADS. FR., *Routes;* GER., *Strassen;* ITAL., *Strada;* SPAN., *Caminos.*

There is a considerably greater diversity in the character and construction of ordinary roads than of those which are used solely by steam locomotives. Upon the latter there is but one description of traffic, that of wheeled vehicles, while upon the former the traffic is of a very miscellaneous kind. The general character of railways differs but little, whereas that of roads varies according to the purposes to which they are applied. Ordinary roads are of two principal types, namely, temporary and permanent roads.

Temporary Roads.—The first idea of a road is a path or track on which a foot-passenger can travel. In the American forests the trees are blazed or marked to show the direction. On the prairies men travel by compass or by the stars; or by watching their own shadows, or noting the direction of the wind. Successive travellers following the same route will tread down a forest path, which is the first step towards road-making. On such a road, rivers will be crossed by swimming or wading, or by rafts; or felled trees might be used on very narrow streams; while ranges of hills would be passed by following the beds of mountain torrents. The employment of animals necessitates the improvement of the roads. The footpaths are widened, the forest is cleared, rude bridges of logs are formed, or rafts made of wood, of empty vessels, or of inflated skins.

Suppose it is required to make a temporary road from one settlement to another in a wild unmapped country. If a traverse were run by compass and chain between the two places, and plotted on paper, the magnetic bearing of the one place from the other would be ascertained, and a straight line could be run between the two by means of the compass. If two flags are set up in the proper direction at some distance apart, then, by means of a third flag brought into line with the two former, a straight line could be run for many miles with a very slight deviation from accuracy. Where a compass is not available, a fire lighted at one place may, by its smoke, enable its direction to be seen from the other.

This line so run, and marked by a trench cut in the ground, will often be a practicable line for the road in a new country; if not, it will at any rate be a valuable guiding line towards which all deviations caused by various obstacles should return. The line so marked out should be cleared for a width of 10, 20, or 30 ft.; a ditch cut on either side to serve as a drain, and the earth excavated thrown in the centre of the road to assist the rain-water to run into the ditches. Inequalities of surface can then be levelled as far as possible. Small streams may be crossed by temporary bridges if wood is available; if not, their banks must be cut down, if necessary, to a gentle slope, so as to enable carts to pass where the stream is dry or nearly so, and such slopes, as well as the bottom of the stream, may be paved, if material is available.

The following is a description of a temporary road of this kind made over the dry bed of the Chenab River in the Punjab, and may be taken as a general example.

The total length for the roadway across the Chenab measures 10,600 running feet, of which 1350 ft. consist of a metalled road; 3500 ft. rest on firm soil, extending from the road embankment to within 1000 ft. of the south side of river, and the remaining 5800 ft. extend across entire sand.

The roadway consists of one layer of grass fascines, each fascine being 24 ft. long, 6 in. in diameter, and tightly bound with grass, packed closely together and covered with 6 in. of clay. On the surface of the clay, and to prevent its cutting into grooves, a very thin layer of loose grass is constantly maintained. An inch of clay is first laid down on the sand, all hollows are filled in and low points somewhat raised, that the foundation may not suffer from the lodgment of water. In other places the finished road is 1 or 2 in. above the sand.

Whatever improvements are made in such roads should be directed towards the most formidable obstacles at first; this is, indeed, self-evident, the strength of a road, as of a beam, being only that of its weakest part; but it is not always easy to determine what are the most formidable obstacles, nor whether it will be more economical to lay out a given sum in raising a portion of embankment, cutting down a hill, improving the surface, or building a bridge, but much of course will depend on the peculiar circumstances of each case.

Plank Roads.—Similarly to the trellis road used on the early railways in the United States, ordinary roads of a temporary character are sometimes constructed exclusively of timber, and are termed plank roads.

The method most generally adopted in constructing plank roads consists in laying a flooring, or track, 8 ft. wide, composed of boards from 9 to 12 in. in width, and 3 in. in thickness, which rest upon two parallel rows of sleepers, or sills, laid lengthwise in the road, and having their centre lines about 4 ft. apart, or 2 ft. from the axis of the road. Sills of various-sized scantling have been used, but experience seems in favour of scantling about 12 in. in width, 4 in. in thickness, and in lengths of not less than 15 to 20 ft. Sills of these dimensions, laid flatwise, and firmly imbedded, present a firm and uniform bearing to the boards, and distribute the pressure they receive over so great a surface, that, if the soil upon which they rest is compact and kept well drained, there can be but little settling and displacement of the road surface, from the usual loads passing over it. The better to secure this uniform distribution of the pressure, the sills of one row are so laid as to break

joints with the other, and to prevent the ends of the sills from yielding, the usual precaution is taken to place short sills at the joints, either beneath the main sills or on the same level with them.

The boards are laid perpendicular to the axis of the road, experience having shown that this position is more favourable to their wear and tear than any other, and is besides the most economical. Their ends are not in an unbroken line, but so arranged that the ends of every three or four project alternately, on each side of the axis of the road, 3 or 4 in. beyond those next to them, for the purpose of presenting a short shoulder to the wheels of vehicles, to facilitate their coming upon the plank surface, when from any cause they may have turned aside. On some roads, the boards have been spiked to the sills, but this is unnecessary, the stability of the boards being best secured by well packing the earth between and around the sills, so as to present, with them, a uniform bearing surface to the boards, and by adopting the usual precautions for keeping the subsoil well drained, and preventing any accumulation of rain-water on the surface. The boards for plank roads should be selected from timber free from the usual defects, such as knots and shakes, which would render it unsuitable for ordinary building purposes, as durability is an essential element in the economy of this class of structures. Boards of 3 in. in thickness offer all the requisites of strength and durability that can be obtained from timber in its ordinary state, in which it is used for plank roads.

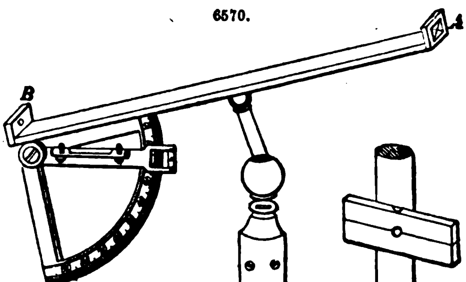
Besides the wooden track of 8 ft., an earthen track of 12 ft. in width is made, which serves as a summer road for light vehicles, and as a turn-out for loaded ones; this, with the wooden track, gives a clear road surface of 20 ft., the least that can be well allowed for a frequented road. It is recommended to lay the wooden track on the right-hand side of the approach of a road to a town or village, for the proper convenience of the rural traffic, as the heavy trade is to the town. The surface of this track receives a cross slope from the side towards the axis of the road outwards of 1 in 32. The surface of the summer road receives a cross slope in the opposite direction of 1 in 16. These slopes are given for the purpose of facilitating a rapid surface drainage. The side drains are placed for this purpose parallel to the axis of the road, and connected with the road surface in a suitable slope.

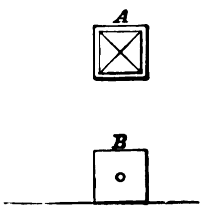
Where, from the character of the soil, good summer roads cannot be had, it will be necessary to make wooden turn-outs, from space to space, to prevent the inconvenience and delay of miry roads. This can be effected by laying at these points a wooden track of double width to enable vehicles meeting, to pass each other. It is recommended to lay these turn-outs on four or five sills, to spring the boards slightly at the centre, and spike their ends to the exterior sills.

The angle of repose, by which the grade of plank roads should be regulated, has not yet been determined by experiment, but as the wooden surface is covered with a layer of clean sand, fine gravel, or tan bark, before it is thrown open to vehicles, and as it in time becomes covered with a permanent stratum of dust, it is probable that this angle will not materially differ from that on a road with a broken-stone surface, like that of M'Adam or of Telford, when kept in a thorough state of repair.

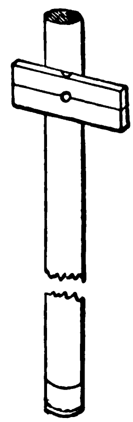
In some of the earlier plank roads made in Canada, a width of 16 ft. was given to the wooden track, the boards of which were laid upon four or five rows of sills. But experience soon demonstrated that this was not an economical plan, as it was found that vehicles kept the centre of the wooden surface, which was soon worn into a beaten track, whilst the remainder was only slightly impaired. This led to the abandonment of the wide track for the one now usually employed, which answers all the purposes of the traffic, and is much more economical, both in the first outlay and for subsequent renewals and repairs. The plank roads possess great advantages in a densely-wooded country, and will be found superior to every other kind as a temporary expedient.

6570.





6571.



6572.

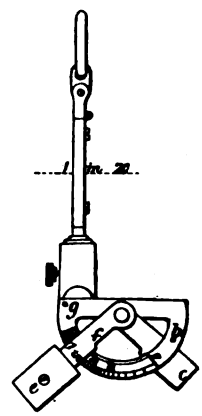
Hill Roads.—The construction of hill roads, which are frequently of only a temporary character, although at times subsequently enlarged and improved so as to come under the other category, increases in difficulty with the quantity of timber met with in the district. Sometimes footpaths may exist, which, although mere tracks, will enable in some degree the nature of the ground to be rightly ascertained. The ordinary spirit-level is unsuited for the operation of surveying, or, as it is termed, tracing out, a hill road. It is too large, and requires a greater delicacy of adjustment and manipulation than can be given to it under the circumstances. The instrument represented in Figs. 6570 to 6572 is often employed in India for the purpose in question, and answers exceedingly well. It goes by the name of the Gunner's Quadrant, being, with a few modifications, a level for setting mortars at their proper angle. The long bar is fitted with sights at either end, and has a universal joint screwed on at its centre. The quadrant is reversed from the position it occupies in the mortar quadrant, having the arc turned inwards, and the radius outwards, towards the tracer. An armature, bearing a small spirit-level at its side, and a vernier to read minutes at one end, works on the arc, which, to enable the level to be used

for tracing either up or down hill without reversion, has an excess arc of some 5° on the upper side of its zero point. The tracing quadrant is fixed to a light stick, shod with iron, of a length sufficient to bring the pin-hole of the sight within easy distance of the eye. The stick should not terminate in a point, or the levels will be vitiated. Its base ought to be about 1½ in. in diameter. The forward staff is rather longer than the foregoing, but has a fixed vane, painted white, whose centre is exactly the same height from the ground as the pin-hole of the quadrant sight. The centre is denoted by a dot in the middle of a black horizontal line.

The tracer holds the instrument in his hand, having adjusted the armature by the scale and vernier to the angle of inclination suited to the slope of the ground. A slope of 1 in 20, corresponding to 2° 52′, or to within a few minutes of 3°, should be the maximum, except for temporary descent into water-courses, which may be 1 in 12, or 4° 45′. The holder of the forward staff goes on a few yards, and is signalled up or down, till the foot of it is resting on the line of the required slope. The tracer has no difficulty in observing the bubble of the level at the same moment as he watches the vane of the staff through the pin-hole sight and cross hairs, and as soon as properly placed, he orders a stake to be driven at its foot. He then moves up to the stake, and sends the staff-bearer forward to take up a fresh position, and so on till the line is staked in. A party follows to open out the line, and when it has been inspected and approved of, the road is finished to the full width, with a side drain.

This simple method of tracing is admirably suited to rough, undulating country, covered with forest, where an ordinary spirit-level cannot be easily carried about or set up, and where extreme accuracy is not imperative, as in the case of permanent roads. Even a practised eye cannot lay out a road on the hill-side that would not be found to depart widely from the uniform slope proposed, unless the instrument has been in hand all the time; eye traces, as they are termed, should therefore be proscribed, except on flattish ground, where the slavish following of the instrument is apt to lead to the marking of a tortuous line. If a cutting through a saddle or spur has to be made, it is usual to denote its commencement and end, by inserting two stakes instead of one, and at descents into streams, the same course must be observed. Great care should be exercised that the latter are formed with due regard to facility of passage, for many an excellent road-trace is marred by insurmountable difficulties at the steep banks of rivers, or headlong ramps.

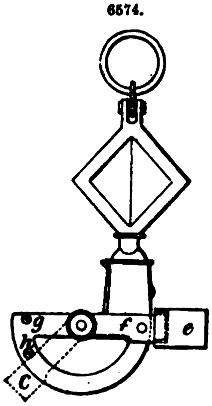
6573.



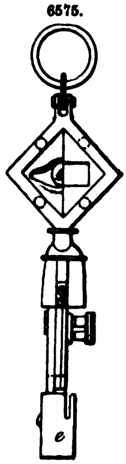
Another instrument used for the same purpose is De Lisle's clinometer, Fig. 6573, and represents the first instrument made. It is in two parts, separating at the dotted line in the figure. The lower part can be fitted on in three positions; for packing in its case, with the weight *e* to the left of the mirror; for descending slopes, with the arc and weight *e* behind the mirror; for ascending slopes, with the arc and weight *e* in front of the mirror.

In the more recent instruments, Figs. 6574 to 6578, the lower part does not draw off, but revolves on the axis of the mirror, and is retained in the required position by a small spring. The semi-circular arc has two radial bars, one *c*, light, the other, *f*, loaded with a weight *e*. For level set the bar *f* against the bar *g*, and bring the light bar *c* home in the groove formed for its reception in the weight *e*. For a slope of 1 in 50 leave *f* against *g*, and move the light bar *c* against the top *h*. For any other slope leave the bar *c* against the top *h*, and set the bevelled edge of bar *f* to the required division on the graduated limb of the arc; see Fig. 6576, where the instrument is set to 1 in 20.

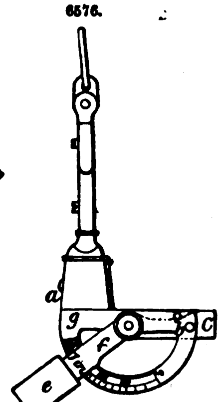
6574.



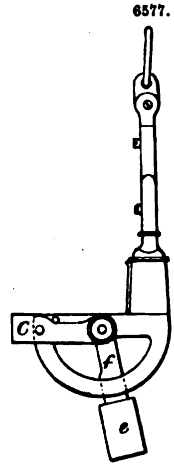
6575.



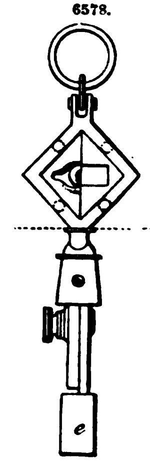
6576.



6577.



6578.



In practice it should be remembered that a flatter slope should be used in tracing than that intended for the finished road, in order to allow for the increased slope due to flattening the curves of

the line. Thus for a road at 1 in 20 the instrument should be set to 1 in 21 or 22, according to the nature of the ground. In using the instrument a levelling staff with sliding vane is convenient. The vane on the staff must be adjusted to the height of the observer's eye. The observer stands at the initial point of the trace, and sends an assistant forward with the staff to any convenient distance; the observer then holds the instrument up by the ring and makes his assistant move the staff up or down the slope of the hill until he gets the reflection of the pupil of his eye in the mirror and the vane to coincide. A stake is then driven in at the foot of the staff. The observer moves forward to this stake and sends his assistant on for the next station, and so on. In taking cross-sections of streams the instrument should be adjusted for level, and the vane on the staff moved up or down at each station until the requisite coincidence is obtained. The level is then read off on the staff and entered in the usual manner. In windy weather it may be convenient to suspend the instrument in a wooden box with sight holes. The box should be mounted on a light staff, and the vane on the levelling staff must be set to the height of the mirror. When the line is staked out and considered satisfactory, a gauge-path should be cut and the line surveyed either by theodolite or spirit-level for the plans and estimates.

The great advantage of this instrument will be found on lines along steep cliffs where a theodolite could not be taken without much risk of injury. It will also save the tedious labour of setting up and levelling a theodolite at numerous successive stations.

The reflecting level, a small instrument that can be put in the waistcoat-pocket, case and all, is a most useful little instrument for tracing out a line of road through the hills. The instrument itself, when drawn out to its full extent, does not exceed 6 in., and is little more than ½ in. in diameter. On the top of it is a small spirit-level, and inside the tube a reflector, so placed, that when looking through the instrument you can observe where the bubble is on the centre of the run, at which time the metal reflector shows just one-half of the air-bubble. The line of vision along the bottom of the reflector is a horizontal line, so that any point which the line intersects is level with the eye of the observer.

For selecting the general line of road, therefore, this instrument is most useful, as it enables you to select points of equal altitude with the point of observation, and thus, for the preliminary survey, it enables you to determine the general direction the road should take, and what points should be closed on.

Before, however, selecting a new line of road, certain points should be determined on, which will altogether depend on the object for which the road is intended. As, for example, if only for a foot-path the gradients may be as great as 1 in 5; a bridle-path, 1 in 7½; laden mules, say, 1 in 10; camels, 1 in 15; wheeled carriages, 1 in 25; and these gradients should never be exceeded.

The average gradients for the whole length of road where the great object is to ascend a hill would probably be, for footpath, 1 in 7½; horses, 1 in 10; mules, laden, 1 in 15; camels, 1 in 20; carts, 1 in 50. The advantage of not being confined to one particular gradient is manifest, as by a change in the gradient the muscles have a different action to perform, so there is not that one constant strain on them.

All that is required when tracing a line up-hill is a hill walking-staff of say 5 ft. in length. When the person engaged in the work is very tall it may be even 5½ ft. long. This staff should have an iron point to fix it firmly in the ground, so that the level which is attached to the top of it may be firmly supported. With a rope 50 ft. long, having a knot on it 37½ ft., and a hatchet for clearing away bush tangle, nothing more is required but stakes for staking out the line.

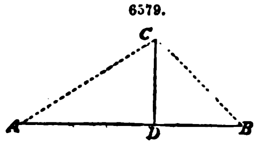
It is evident that, having an instrument looking along a horizontal line, if a point on the hill-side be fixed on the same level as that of the instrument, and 37½ ft. distant from it, the gradient is exactly 1 in 7½, and at 57 ft. 1 in 10, if measured from the top of the staff; but as this may not be convenient, allowance can be made for the extra length of the hypothenuse, but practically it is nothing, and may be left out. It may be said, therefore, that from 37½ to 50 ft. is the length of the tether when a bridle-road is to be traced out, and stakes driven at the same level as the instrument will give a gradient of 1 in 7½ at 37½ ft., so all that is required is to see the ground at these distances, or any distances between, to keep the gradient right while working up-hill. This, however, entails a good deal of clearing away bush, so it is better, if possible, to work down-hill. In this case a 10-ft. rod is required, double the height of the instrument, and all one has to do is to look at the top of the rod and see that it is at the proper level.

Where the gradients are less steep, the rope has simply to be lengthened; as, for example, where the gradient is to be 1 in 52, the length of rope must be $25 \times 5 = 125$ ft., and any distance beyond the 125 ft. must make the gradient less steep.

The stakes laid down are on the centre line of the intended road, and in order to open it out a strong line must be stretched from the one stake to the other. This allows of the gradient being worked to with sufficient accuracy.

Permanent Roads.—Selection of Route.—Suppose that it is desired to form a road between two distant towns, A and B, Fig. 6579, and let us, for the present, neglect altogether the consideration of the physical features of the intervening country, assuming that it is equally favourable whatever line we select. Now, at first sight, it would appear that under such circumstances a perfectly straight line drawn from one town to the other would be the best that could be chosen. On a more careful examination, however, of the locality, we may find that there is a third town, C, situated somewhat on one side of the straight line which we have drawn from A to B; and although our primary object is to connect only the two latter, that it would nevertheless be of considerable service if the whole of the three towns were put into mutual connection with each other. Now this may be effected in three different ways, any one of which might, under certain circumstances, be the best. In the first place, we might, as originally suggested,

6579.



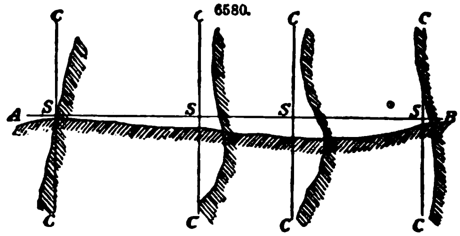
form a straight road from A to B, and, in a similar manner, two other straight roads from A to C, and from B to C, and this would be the most perfect way of effecting the object in view, the distance between any two of the towns being reduced to the least possible. It would, however, be attended with considerable expense, and it would be requisite to construct a much greater length of road than according to the second plan, which would be to form, as before, a straight road from A to B, and from C to construct a road which should join the former at a point D, so as to be perpendicular to it. The traffic between A or B and C would proceed to the point D, and then turn off to C. With this arrangement, while the length of the roads would be very materially decreased, only a slight increase would be occasioned in the distance between C and the other two towns. The third method would be to form only the two roads A C and C B, in which case the distance between A and B would be somewhat increased, while that between A and C, or B and C, would be diminished, and the total length of road to be constructed would also be lessened.

As a general rule it may be taken, that the last of these methods is the best, and most convenient for the public, that is to say, that if the physical character of the country does not determine the course of the road, it will generally be found best not to adopt a perfectly straight line, but to vary the line so as to pass through all the principal towns near its general course. According to the first arrangement, any vehicles established to convey passengers or goods between the two terminal towns would pass through all those which were intermediate, while, if the straight line and branch-road system were adopted, it would be requisite also to have a branch service to meet the service on the main line.

In laying out a road in an old country which has been long inhabited, and in which the position of the various towns requiring road accommodation is already determined, we are left less at liberty in the choice and selection of the line of road, and must be guided in that choice by different considerations to those which would determine the line of a road made through a new country, where the only object is to establish the easiest and best road between two distant stations. In the first case we should take into consideration the position of the various towns and other inhabited districts situated near the intended road, and its course would be, to a certain extent, controlled thereby; while, in the second case, we should simply examine the physical characters of the country, and base all our proceedings on the result. Whichever of these two cases, however, may have to be dealt with, in the ultimate selection and adoption of the line of road between those points which are fixed by other circumstances, the same careful examination of the physical character of the country should be made, and the same principles should control the choice.

A very good idea of the best direction for a road may be obtained by laying out a series of preliminary lines, as in Fig. 6580. Let A B be a portion of the intended line, and C C the breadth of country under consideration. At any suitable distances select stations S S S, their distances apart depending on the changes of level, and let the principal line A B, and also the cross lines C C, C C, Fig. 6580, be accurately levelled, and then drawn, on the plan of the line of the road. If the distance C C is required to be considerable, perhaps an additional line in the principal direction may be necessary. The etched lines show the form of the surface at the lines A B, C C on the plan of the latter being sections at right angles to A B, there is no difficulty in seeing the extent of cutting or of embankment that may be avoided by varying the position of the intended line. A plan of this description to a person conversant with sections is as good as a model of the country. In selecting the line for a permanent road, useless ascents should be avoided as much as possible, that is, ascending where a subsequent descent must be made, and the reverse. When a line of road is encumbered with numerous and extensive useless ascents, the wasteful expenditure of power in the conveyance of goods is very great, as the number of feet actually ascended is increased many times more than is necessary, if such height, when once gained, were not lost again. As one instance, amongst others, of the serious injury which the public sustains by this system of road-making, the road between London and Barnet may be mentioned, on which the total number of perpendicular feet that a horse must now ascend, is upwards of 1300, although Barnet is only 500 ft. higher than London, and in going from Barnet to London, a horse must ascend 800 ft., although London is 500 ft. lower than Barnet. Another instance of this defect in road engineering is observable in the line of the old road across the Island of Anglesea, on which a horse was obliged to ascend and descend 1283 perpendicular feet more than was found necessary by Telford when he laid out the present new line, as shown by the annexed Table ;—

6580.



	Height of Summit above High Water.	Total Rise and Fall.	Length.
			miles. yards.
Old road	339	3540	24 428
New road	193	2257	21 1596
Difference	146	1283	2 592

In choosing the best direction for a line of roadway, the rate of inclination which can be obtained, with a moderate outlay of capital in cuttings and embankments, is a consideration of greater importance than the mere maintaining of a direct line.

Gradients and Tractive Resistance.—In the case of an ordinary metalled road the maximum gradient is fixed by two considerations, one relating to the power expended in ascending, the other to the acceleration in descending the incline.

The ascent should not be so steep as to prevent the horses taking up the full load which they can draw on the level. Now a horse will exert for a short time twice the average tractive pull which he can exert continuously throughout a day's work. Hence, so long as the resistance on the gradient is not more than double the resistance on the level, the horse will be able to take up the full load which he is capable of drawing. If the resistance to traction on metalled roads is taken at one-thirtieth of the load on the wheels, then the maximum gradient should not exceed 1 in 30; because on that slope the gradient resistance is equal to the resistance on the level, and the total resistance exactly doubled.

Again, in regard to descending, it may be assumed that the slope should not be so great that the gravity acting down the slope should exceed the resistance to traction, because in that case the carriages or wagons would tend to accelerate in velocity under the action of gravity alone, and brakes would have to be used to control the descent, causing a waste of work in friction. This consideration again fixes the maximum gradient desirable on metalled roads at 1 in 30. For a short distance, steeper gradients of 1 in 20 and 1 in 15 may be adopted with economy, but their number should be as few as possible.

Wheel-carriages and sledges are the vehicles capable of plying on roads. The latter are only suitable for roads in which the surface is either too soft or too steep to admit of the use of the other description. The tractive resistance of sledges has not been accurately ascertained. It is stated by Kossak that the resistance of an iron-shod sledge on hardened snow is about one-thirtieth of the gross load. The resistance of wheel-carriages on roads consists of a constant quantity and a quantity increasing with the velocity of transit. Putting R for the radius of the wheels in inches, V for the velocity in feet per second, A and B for the two constants, we have for F, the proportion to the gross load, $F = \frac{\{A + B\,(V - 3 \cdot 28)\}}{R}$. When the carriages are on springs F, for wheels of 18 in. diameter, and V equals 14·67 and 7·33 respectively, the values for A are 0·4 to 0·55 for good broken stone roads and 0·27 to 0·39 for pavements. The corresponding values for B are 0·025 and 0·068 to 0·03. When V has a value of 14·67 that of F is for roads of broken stone 0·038 to 0·046, and for pavements 0·060 to 0·041. When V = 7·33, F has values of 0·028 to 0·036, and 0·030 to 0·028. When the carriages have no springs, the value of the constant B is 3·5 that for carriages with springs. Table I. is deduced from experiments made by John Macneill.

Table I.

	F.
Stone pavement	0·015
Broken-stone road on firm foundation	0·020
Broken-stone road on flint foundation	0·029
Gravel road	0·067
Soft sandy and gravelly ground	0·143

If W be the greatest gross load to be conveyed, S the sine of the angle of the inclination of the gradient, then the maximum resistance will equal W (F + S). If P be the greatest tractive force which can be exerted in ascending the gradient, then we have P not less than W (F + S), or S should not be greater than $\frac{P}{W} - F$. This condition is essential, and fixes the inclination of the ruling gradient.

The following are the general results of the experiments made by Morin upon this subject;—

1st. The traction is directly proportional to the load, and inversely proportional to the diameter of the wheel.

2nd. Upon a paved or hard macadamized road, the resistance is independent of the width of the tire, when it exceeds from 3 to 4 in.

3rd. At a walking pace the traction is the same, under the same circumstances, for carriages with springs and without them.

4th. Upon hard macadamized and upon paved roads, the traction increases with the velocity; the increments of traction being directly proportional to the increments of velocity above the velocity 3·28 ft. a second, or about 2¼ miles an hour. The equal increment of traction thus due to each equal increment of velocity is less as the road is more smooth, and the carriage less rigid or better hung.

5th. Upon soft roads of earth, or sand, or turf, or roads fresh and thickly gravelled, the traction is independent of the velocity.

6th. Upon a well-made and compact pavement of hewn stones, the traction at a walking pace is not more than three-fourths of that upon the best macadamized roads under similar circumstances, and at a trotting pace it is equal to it.

7th. The destruction of the road is in all cases greater, as the diameters of the wheels are less, and it is greater in carriages without than with springs.

The general results obtained by John Macneill are given in the following Table, the numbers in which exhibit the tractive force requisite to move a weight of a ton under ordinary circumstance, at a very low velocity upon the several kinds of road mentioned.

TABLE II.

Description of Road.	Force, in lbs., required to move a ton.
On a well-made pavement	33
On a road made with 6 in. of broken stone of great hardness, laid either on a foundation of large stones, set in the form of a pavement, or upon a bottoming of concrete	46
On an old flint road, or a road made with a thick coating of broken stone, laid on earth	65
On a road made with a thick coating of gravel, laid on earth	147

Macneill has also given the following formulæ for calculating the resistance to traction on various kinds of roads. They have been deduced from a considerable number of experiments made on the different kinds of road specified below, with carriages moving at various velocities. Putting R for the force required to move the carriage, W the weight of the carriage, w that of the load, all expressed in pounds, v the velocity in feet a second, and c a constant number, which depends upon the surface over which the carriage is drawn, and the value of which for several different kinds of roads is as follows;—

On a timber surface..	$c = 2$
On a paved road	$c = 2$
On a well-made broken-stone road, in a dry, clean state	$c = 5$
On a well-made broken-stone road, covered with dust	$c = 8$
On a well-made broken-stone road, wet and muddy ..	$c = 10$
On a gravel or flint road, in a dry, clean state	$c = 13$
On a gravel or flint road, in a wet and muddy state..	$c = 32$

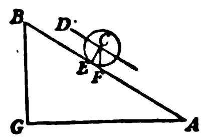
We have, in the case of a common stage wagon, $R = \frac{W + w}{93} + \frac{w}{40} + cv$; and in the case of a stage coach, $R = \frac{W + w}{100} + \frac{w}{40} + cv$.

As an example. What force would be required to move a stage coach weighing 2060 lbs., and having a load of 1100 lbs., at a velocity of 9 ft. a second along a broken-stone road covered with dust?

Here we have $\frac{2060 + 1100}{100} + \frac{1100}{40} + 8 \times 9 = 131 \cdot 1$ lbs. for the force required.

We may now consider the additional resistance which is occasioned when the road, instead of being level, is inclined in a greater or less degree. In order to simplify the question, let us suppose the whole weight to be supported on one pair of wheels, and that the tractive force is applied in a direction parallel to the surface of the road. On this supposition let A B in Fig. 6581 represent a portion of the inclined road, C being a carriage just sustained in its position by a force acting in the direction C D. It is evident that the carriage is kept in its position by three forces, namely, by its own weight W acting in the vertical direction C F, by the force F applied in the direction C D, parallel to the surface of the road, and by the pressure P which the carriage exerts against the surface of the road acting in the direction C E, perpendicular to the same. To determine the relative magnitude of these three forces, draw the horizontal line A G, and the vertical one B G; then, since the two lines C F and B G are parallel, and are both cut by the line A B, they must make the two angles C F B and A B G equal; also the two angles C E F and A G B are equal, being both right angles; therefore the remaining angles F C E and B A G are equal, and the two triangles C F E and A B G are similar. And as the three sides of the former are proportional to the three forces by which the carriage is sustained, so also are the three sides of the latter, namely, A B, or the length of the road is proportional to W, or the weight of the carriage B G, or the vertical rise in the same to F, or the force required to sustain the carriage on the incline, and A G on the horizontal distance in which this rise occurs to P, or the force with which the carriage presses upon the surface of the road.

6581.



We have therefore W : A B :: F : G B, and W : A B :: P : A G. And if we give to A G such a value that the vertical rise of the road is exactly 1 ft., we shall have

$$F = \frac{W}{AB} = \frac{W}{\sqrt{AG^2 + 1}} = W . \sin . \beta, \text{ and } P = \frac{W . AG}{AB} = \frac{W . AG}{\sqrt{AG^2 + 1}} = W . \cos . \beta,$$

in which β is the angle B A G.

Example.—What is the force required to sustain a carriage weighing 3270 lbs. upon a road, the inclination of which is 1 in 30, and what is the pressure of the same upon the surface of the road?

Here the horizontal length of the road A G being 30, the inclined length $AB = \sqrt{AG^2 + 1}$ is $30 \cdot 017$, and we have, by the first rule, $3270 \div 30 \cdot 017 = 108 \cdot 93$ lbs. for the force required to sustain the carriage on the road; and, by the second rule, $(3270 \times 30) \div 30 \cdot 017 = 3269 \cdot 9$ lbs. for the pressure of the carriage upon the surface of the road.

Since the pressure of a carriage on a sloping road is found by multiplying its weight by the horizontal length of the road, and dividing by the inclined length, and as the former is always less than the latter, it follows that the force with which a carriage bears upon an inclined road is less

than its actual weight, as will be seen in the foregoing example, in which it is about 2 lbs. less. Unless the inclination is very steep, it is not necessary to calculate the pressure, which may be assumed to be equal to the weight of the carriage.

If R expresses the resistance which has to be overcome in moving any particular carriage at a given rate upon a horizontal road, then R × F will be the resistance upon ascending a hill, and R − F upon descending a hill, with the same velocity, in both cases neglecting the decrease in the weight of the carriage produced by the inclination of the road. Taking, however, this decrease into consideration, the following modification in the formulæ will be requisite to adapt them to an inclined road; $R = \left(\frac{W + w}{93} + \frac{w}{40}\right) . \cos. \beta \mp (W + w) . \sin. - \beta + c v$. in the case of a common stage wagon, and in that of a stage coach, $R = \left(\frac{W + w}{100} + \frac{w}{40}\right) . \cos. \beta \mp (W + w) . \sin. \beta + c v$. the upper sign being taken when the vehicle is drawn down the incline, and the lower when it is drawn up the same.

Neglecting the decrease in the weight of the carriage, in order to ascertain the resistance in passing up or down a hill, we have only to calculate by the rule already given the resistance on a level road, to which, if the carriage ascends the hill, we must add, or if it descends, subtract, the force requisite to sustain the carriage on the inclined road, calculated by the proper rule. The sum or difference, as the case may be, will express the resistance required.

As an example, let us take, as before, the case of a stage coach weighing 2060 lbs., besides a load of 1100 lbs., and having to be moved at a velocity of 9 ft. a second along a broken-stone road whose surface is covered with dust, and inclined at the rate of 1 in 30.

Then the force to sustain the coach on this slope will be $\frac{3160}{30} = 105{\cdot}3$ lbs., which, added to the force already found as being requisite to move the same coach on a level road, will be

$$(105{\cdot}3 + 131{\cdot}1 =)\ 236{\cdot}4 \text{ lbs.}$$

for the force required to move the coach with a velocity of 9 ft. a second up an inclination of 1 in 30; and subtracted from the same, will be $(131{\cdot}1 - 105{\cdot}3 =)\ 25{\cdot}8$ lbs., the force required to move the coach with the same velocity down the same inclination.

The same example worked by the formula will give

$$\left(\frac{2060 + 1100}{100} + \frac{1100}{40}\right) {\cdot}9995 + (2060 + 1100)\ {\cdot}0333 + 8 \times 9 = 236{\cdot}3 \text{ lbs.}$$

when the carriage is drawn up the incline, and

$$\left(\frac{2060 + 1100}{100} + \frac{1100}{40}\right) {\cdot}9995 - (2060 + 1100)\ {\cdot}0333 - 8 \times 9 = 25{\cdot}84 \text{ lbs.}$$

when the carriage is drawn down the incline, the result being the same as that given by the rule.

Table III. has been calculated in order to show with sufficient exactness for most practical purposes the force required to draw carriages over inclined roads, and the comparative advantage of such roads and those which are perfectly level. The first column expresses the rate of inclination, and the second the equivalent angle; the two next columns contain the force requisite to draw a common stage wagon weighing with its load 6 tons, at a velocity of 4·4 ft. a second, or 3 miles an hour, along a macadamized road in its usual state, both when the hill ascends and when it descends; the fifth and sixth columns contain the length of level road which would be equivalent to a mile in length of the inclined road; that is, the length which would require the same mechanical force to be expended in drawing the wagon over it as would be necessary to draw it over a mile of the inclined road; the four next columns contain the same information as the four last described, only with reference to a stage coach supposed to weigh with its load 3 tons, and to travel at the rate of 8·8 ft. a second, or 6 miles an hour.

TABLE III.

Rate of Inclination.	Angle with the horizon.	For a Stage Wagon.				For a Stage Coach.			
		Force required to draw the wagon *up* the incline.	Force required to draw the wagon *down* the incline.	Equivalent length of level road for an *ascending* wagon.	Equivalent length of level road for a *descending* wagon.	Force required to draw the coach *up* the incline.	Force required to draw the coach *down* the incline.	Equivalent length of level road for an *ascending* coach.	Equivalent length of level road for a *descending* coach.
	° ′ ″	lbs.	lbs.	miles.	miles.	lbs.	lbs.	miles.	miles.
1 in 600	0 5 44	286	241	1·085	·9150	373	350	1·030	·9690
„ 575	0 5 59	287	240	1·088	·9116	373	350	1·032	·9676
„ 550	0 6 15	288	239	1·093	·9074	374	349	1·033	·9662
„ 525	0 6 33	289	238	1·097	·9029	374	349	1·035	·9646
„ 500	0 6 53	291	237	1·102	·8979	375	318	1·037	·9629
„ 475	0 7 14	292	235	1·107	·8926	376	347	1·039	·9605
„ 450	0 7 38	294	234	1·113	·8869	377	347	1·041	·9588
„ 425	0 8 5	295	232	1·120	·8801	377	346	1·043	·9563
„ 400	0 8 36	297	230	1·128	·8725	378	345	1·046	·9535
„ 375	0 9 10	300	228	1·136	·8642	380	344	1·049	·9505
„ 350	0 9 49	302	225	1·146	·8543	381	342	1·053	·9469

TABLE III.—*continued.*

Rate of inclination.	Angle with the horizon.	For a Stage Wagon. Force required to draw the wagon *up* the incline.	Force required to draw the wagon *down* the incline.	Equivalent length of level road for an *ascending* wagon.	Equivalent length of level road for a *descending* wagon.	For a Stage Coach. Force required to draw the coach *up* the incline.	Force required to draw the coach *down* the incline.	Equivalent length of level road for an *ascending* coach.	Equivalent length of level road for a *descending* coach.
	° ′ ″	lbs.	lbs.	miles.	miles.	lbs.	lbs.	miles.	miles.
1 in 325	0 10 35	305	222	1·157	·8433	382	341	1·056	·9430
„ 300	0 11 28	309	219	1·170	·8301	384	339	1·061	·9381
„ 290	0 11 51	310	217	1·176	·8245	385	338	1·064	·9358
„ 280	0 12 17	312	216	1·182	·8179	386	338	1·066	·9336
„ 270	0 12 44	314	214	1·189	·8111	386	337	1·068	·9314
„ 260	0 13 13	315	212	1·196	·8039	387	336	1·071	·9286
„ 250	0 13 45	317	210	1·204	·7963	388	335	1·074	·9259
„ 240	0 14 19	320	208	1·212	·7876	390	334	1·077	·9226
„ 230	0 14 57	322	205	1·222	·7785	391	332	1·080	·9192
„ 220	0 15 37	325	203	1·232	·7683	392	331	1·084	·9156
„ 210	0 16 22	328	200	1·243	·7573	394	330	1·088	·9115
„ 200	0 17 11	331	197	1·255	·7451	395	328	1·092	·9071
„ 190	0 18 6	334	193	1·268	·7319	397	326	1·097	·9024
„ 180	0 19 6	338	189	1·283	·7171	399	324	1·103	·8968
„ 170	0 20 13	343	185	1·300	·7004	401	322	1·109	·8908
„ 160	0 21 29	348	180	1·319	·6814	404	320	1·116	·8839
„ 150	0 22 55	353	174	1·341	·6587	406	317	1·123	·8761
„ 140	0 24 33	360	168	1·364	·6359	410	314	1·132	·8673
„ 130	0 26 27	367	160	1·392	·6079	413	310	1·142	·8573
„ 120	0 28 39	376	152	1·425	·5752	418	306	1·154	·8451
„ 110	0 31 15	386	142	1·451	·5491	423	300	1·169	·8308
„ 100	0 34 23	398	129	1·510	·4903	429	294	1·185	·8142
„ 95	0 36 11	405	122	1·537	·4634	432	291	1·195	·8045
„ 90	0 38 12	413	114	1·566	·4338	436	287	1·206	·7937
„ 85	0 40 27	422	106	1·600	·4004	441	282	1·219	·7801
„ 80	0 42 58	432	96	1·637	·3629	446	278	1·232	·7677
„ 75	0 45 51	443	85	1·680	·3204	451	272	1·247	·7522
„ 70	0 49 7	456	72	1·728	·2719	457	266	1·265	·7345
„ 65	0 52 54	470	57	1·784	·2161	465	258	1·285	·7143
„ 60	0 57 18	488	40	1·850	·1505	474	250	1·309	·6903
„ 55	1 2 30	508	19	1·926	·0736	484	239	1·337	·6620
„ 50	1 8 6	533	..	2·019	..	496	227	1·371	·6283
„ 45	1 16 24	562	..	2·133	..	511	212	1·412	·5871
„ 40	1 25 57	600	..	2·274	..	530	194	1·464	·5354
„ 35	1 38 14	648	..	2·456	..	554	170	1·530	·4690
„ 34	1 41 8	659	..	2·499	..	559	164	1·546	·4535
„ 33	1 44 12	671	..	2·544	..	565	158	1·562	·4370
„ 32	1 47 27	684	..	2·593	..	572	152	1·580	·4193
„ 31	1 50 55	697	..	2·644	..	578	145	1·599	·4007
„ 30	1 54 37	712	..	2·699	..	586	138	1·619	·3805
„ 29	1 58 34	727	..	2·758	..	593	130	1·640	·3592
„ 28	2 2 5	744	..	2·820	..	602	122	1·663	·3363
„ 27	2 7 2	762	..	2·888	..	610	113	1·688	·3119
„ 26	2 12 2	781	..	2·960	..	620	103	1·714	·2854
„ 25	2 17 26	801	..	3·038	..	630	93	1·743	·2566
„ 24	2 23 10	823	..	3·120	..	641	82	1·774	·2257
„ 23	2 29 22	847	..	3·213	..	653	69	1·808	·1919
„ 22	2 36 10	874	..	3·313	..	666	56	1·844	·1554
„ 21	2 43 35	903	..	3·423	..	681	42	1·884	·1150
„ 20	2 51 21	933	..	3·538	..	696	26	1·926	·0730
„ 19	3 0 46	970	..	3·677	..	714	8	1·977	·0221
„ 18	3 10 47	1009	..	3·826	..	734	..	2·032	..
„ 17	3 21 59	1053	..	3·991	..	756	..	2·092	..
„ 16	3 34 35	1102	..	4·178	..	780	..	2·160	..
„ 15	3 48 51	1157	..	4·388	..	807	..	2·234	..
„ 14	4 5 14	1221	..	4·629	..	839	..	2·322	..
„ 13	4 23 56	1294	..	4·906	..	875	..	2·423	..
„ 12	4 45 49	1379	..	5·229	..	918	..	2·540	..
„ 11	5 11 40	1480	..	5·611	..	968	..	2·679	..
„ 10	5 42 58	1600	..	6·067	..	1028	..	2·846	..
„ 9	6 20 25	1747	..	6·623	..	1101	..	3·048	..
„ 8	7 7 30	1929	..	7·315	..	1192	..	3·300	..
„ 7	8 7 48	2162	..	8·199	..	1308	..	3·621	..

The foregoing Table may be considered as affording a view of the comparative disadvantage of hilly roads with light and heavy traffic. The stage wagon, weighing 6 tons, and travelling at the speed of 3 miles an hour, may be taken as a fair average for goods traffic, and the stage coach, weighing 3 tons, and running 6 miles an hour, for passenger traffic. From the Table we perceive that hills act much more unfavourably on the former than on the latter. The force which would be requisite to move the wagon on a level road would be 264 lbs., and that to move the coach 362 lbs., being an excess of 98 lbs. for the traction of the coach; but with a road inclined at the rate of 1 in 600, this excess is only (373−286) = 87 lbs., and when the inclination of the road amounts to about 1 in 70 the forces required to draw them become equal. As the inclination of the road increases beyond this, the excess of the force requisite to draw the wagon over that necessary to move the coach increases rapidly, until, at an inclination of 1 in 7, it amounts to (2162 − 1308) = 854 lbs.

If we compare the forces required to draw either the wagon or coach up and down any given incline, we shall find that the former is as much greater than the force required on a level road as the latter is less than the same. It might thence be concluded that in the case of a vehicle passing alternately along the road, no real loss would be occasioned by the inclination of the road, since as much power would be gained in the descent of the hill as was lost in its ascent. Such is not, however, practically the fact, for while the inclinations of the road render it necessary in the ascending journey to have either a greater number or more powerful horses than would be requisite if the road were entirely level, no corresponding reduction can be made in the descending journey, as there must be horses sufficient to draw the vehicle along the level portions of the road.

TABLE IV.

Gradient.	Vertical rise in a mile.	Vertical rise in a chain.	Angle θ which gradient makes with the horizontal.	Sine of angle θ.	Gradient.	Vertical rise in a mile.	Vertical rise in a chain.	Angle θ which gradient makes with the horizontal.	Sine of angle θ.
			° ′ ″					° ′ ″	
1 in 10	528·0	6·60	5 42 58	·09960	1 in 60	88·0	1·10	0 57 18	·01667
„ 11	480·0	6·00	5 11 40	·09054	„ 65	81·2	1·02	0 52 54	·01539
„ 12	440·0	5·50	4 45 59	·08309	„ 70	75·4	·94	0 49 7	·01429
„ 13	406·1	5·08	4 23 56	·07670	„ 75	70·4	·88	0 45 51	·01334
„ 14	377·1	4·71	4 5 14	·07128	„ 80	66·0	·82	0 42 58	·01250
„ 15	352·0	4·40	3 48 51	·06652	„ 85	62·1	·78	0 40 27	·01177
„ 16	330·0	4·12	3 34 35	·06238	„ 90	58·7	·69	0 38 12	·01111
„ 17	310·6	3·88	3 21 59	·05872	„ 95	55·6	·69	0 36 11	·01053
„ 18	293·3	3·67	3 10 47	·05547	„ 100	52·8	·66	0 34 23	·01000
„ 19	277·9	3·47	3 0 46	·05256	„ 110	48·0	·60	0 31 15	·00909
„ 20	264·0	3·30	2 51 21	·04982	„ 120	44·0	·55	0 28 39	·00833
„ 21	251·4	3·14	2 43 35	·04757	„ 130	40·6	·51	0 26 27	·00769
„ 22	240·0	3·00	2 36 10	·04541	„ 140	37·7	·47	0 24 33	·00714
„ 23	229·6	2·87	2 29 22	·04344	„ 150	35·2	·44	0 22 55	·00666
„ 24	220·0	2·75	2 23 10	·04163	„ 160	33·0	·41	0 21 29	·00625
„ 25	211·2	2·64	2 17 26	·03997	„ 170	31·1	·39	0 20 13	·00588
„ 26	203·1	2·54	2 12 2	·03840	„ 180	29·3	·37	0 19 6	·00556
„ 27	195·5	2·42	2 7 2	·03694	„ 190	27·8	·35	0 18 6	·00527
„ 28	188·5	2·36	2 2 5	·03551	„ 200	26·4	·33	0 17 11	·00500
„ 29	182·1	2·28	1 58 34	·03448	„ 210	25·1	·31	0 16 22	·00476
„ 30	176·0	2·20	1 54 37	·03333	„ 220	24·0	·30	0 15 37	·00454
„ 31	170·3	2·13	1 50 55	·03226	„ 230	23·0	·29	0 14 57	·00435
„ 32	165·0	2·06	1 47 27	·03125	„ 240	22·0	·27	0 14 19	·00417
„ 33	160·0	2·00	1 44 12	·03031	„ 250	21·1	·26	0 13 45	·00400
„ 34	155·3	1·94	1 41 8	·02941	„ 260	20·3	·25	0 13 13	·00385
„ 35	150·9	1·88	1 38 14	·02857	„ 270	19·6	·24	0 12 44	·00370
„ 36	146·7	1·86	1 35 28	·02777	„ 280	18·9	·24	0 12 17	·00357
„ 37	142·7	1·78	1 32 53	·02702	„ 290	18·2	·23	0 11 51	·00345
„ 38	138·9	1·74	1 30 27	·02631	„ 300	17·6	·22	0 11 28	·00334
„ 39	135·4	1·69	1 28 8	·02563	„ 325	16·2	·20	0 10 35	·00308
„ 40	132·0	1·65	1 25 57	·02500	„ 350	15·1	·19	0 9 49	·00267
„ 41	128·8	1·61	1 23 50	·02438	„ 375	14·0	·18	0 9 10	·00267
„ 42	125·7	1·57	1 21 50	·02380	„ 400	13·2	·17	0 8 36	·00250
„ 43	122·8	1·53	1 19 56	·02325	„ 425	12·4	·16	0 8 5	·00235
„ 44	120·0	1·50	1 18 7	·02272	„ 450	11·7	·15	0 7 33	·00222
„ 45	117·3	1·47	1 16 24	·02222	„ 475	11·1	·14	0 7 14	·00210
„ 46	114·8	1·44	1 14 43	·02173	„ 500	10·6	·13	0 6 53	·00200
„ 47	112·3	1·40	1 13 8	·02127	„ 525	10·1	·12	0 6 33	·00191
„ 48	110·0	1·37	1 11 37	·02083	„ 550	9·6	·12	0 6 15	·00182
„ 49	107·7	1·35	1 10 9	·02040	„ 575	9·2	·11	0 5 59	·00174
„ 50	105·6	1·32	1 8 6	·01981	„ 600	8·8	·11	0 5 44	·00167
„ 55	96·0	1·20	1 2 30	·01818					

In a practical point of view, therefore, we may consider that the fifth and ninth columns in Table III. express the length of the level road which would be equivalent to a mile of road with the stated inclination, the former giving the result for heavy traffic, and the latter for passenger traffic. For instance, opposite 1 in 75, we find in the ninth column 1·247 mile, or nearly a

mile and a quarter, stated as the length of a road having that inclination which would be equivalent to one mile of a similar road perfectly level, because the same force would be requisite to move a coach of 3 tons at a velocity of 6 miles an hour along one as along the other. Although, however, they might be considered equal as far as the power requisite for traction was concerned, in other respects one might be more advantageous than the other; as, for instance, the shorter road would cost least for repairing, and would occupy least time in being passed over. Table III., therefore, merely expresses the equivalent length as far as the mechanical power required for the traction is concerned. The relative merits in other respects depend generally upon so many various circumstances as to render it quite impossible to lay down any specific rules for their determination.

In Table IV. are given several valuable data for laying down the gradients on roads. The first column gives the gradient expressed in the proportion of the horizontal length to that of the perpendicular height. The second and third columns show the vertical rise in miles and chains respectively. The fourth column contains the angle of inclination with the horizontal, and the last column the sine of the same angle, which will be found to facilitate the necessary calculations.

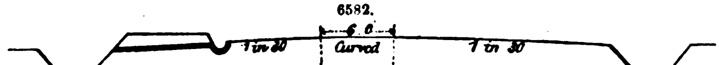
Cross-section of Roads.—The subject of the width and transverse form which should be given to roads must now be considered. As regards the first, a wide road is the best. It is an error to suppose that the cost of repairing a road depends entirely upon the extent of its surface, and consequently increases in the exact ratio of its width. The cost of a mile of road depends more upon the extent and nature of the traffic, and unless extremes be taken, it may be asserted that the same quantity of material would be necessary for the repair of a road, whether wide or narrow, which was subjected to the same amount of traffic. On the narrow road, the traffic, being confined more to one track, would wear the road more severely than when spread over a larger surface. The expense of spreading the material over the wider road would be somewhat greater, but the cost of the materials might be taken as the same. One of the advantages of a wide road is, that the wind and sun exercise more influence in keeping its surface dry. The first cost of a wide road is certainly greater than that of a narrow one, and that nearly in the ratio of its increased width.

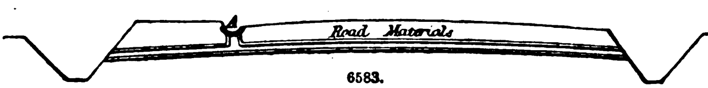
For roads situated between towns of any importance, and exposed to much traffic, the width should certainly not be less than 30 ft., besides a footpath of 6 ft. In the immediate vicinity of large towns and cities, the width should be still further increased. No specific rules can, however, be given for the width in such situations, as experience will soon show the width which is requisite in any given situation.

The form to be given to the cross-section of a road is a subject of much importance, and one upon which much difference of opinion exists. Some advocate a considerable curvature in the upper surface of the road, with the view of facilitating the drainage of its surface, while others object to a road being much curved. Again, some roads have been formed on a flat surface transversely, and others with a dip to the formation surface each way from the centre, on the supposition that the drainage of the road will be thereby facilitated.

One of the best forms which could be given to a road, is that its cross-section should be formed of two straight lines inclined at the rate of about 1 in 30, and united at the centre or crown of the road by a segment of a circle, having a radius of about 90 ft. This form of section is shown in Fig. 6582, and the rate of inclination there given is quite sufficient to keep the surface of a road drained, provided it is in good order and free from ruts. If such is not the case, no amount of convexity which could be given to the road would be of any avail, as the water would still remain in the hollows or furrows. This form of cross-section is equally adapted to all widths of road, as the straight lines have merely to be extended at the same rate of inclination, until they meet the side of the road.

6582.





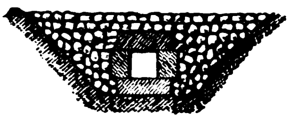
6583.

Drainage of Roads.—Too much attention cannot be paid to the drainage of roads, both as regards their upper surface, and that of the substructure on which they rest. To assist the surface drainage, the road should be formed with the transverse section shown in Fig. 6583, and on each side of the road a ditch should be formed of sufficient capacity to receive all water which can fall upon the road, and of such a depth, and with a sufficient declivity, to conduct the same freely away. When footpaths have to be constructed on the sides of the roads, a channel or water-course should be formed between them, and small drains, formed of tiles or earthen tubes, such as are used for under-draining lands, should be laid under the footpath, at such a level as to take off all the water which may collect in this channel, and convey it into the ditch.

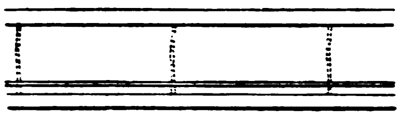
In the best-constructed roads, these side channels should be paved with flints or pebbles. The drains under the footpath should be introduced about every 60 ft., and should have the same inclination, namely, 1 in 30, as used for the sides of the road, Fig. 6582; a greater inclination would be objectionable. It is a very frequent mistake to give too full a fall to small drains, the only effect of which is to produce such a current through them as to wash away or undermine the ground around them, and ultimately cause their own destruction. When a drain is once closed by any obstruction, no amount of fall which could be given to it will again clear the passage, while a drain, with a considerable current through it, is much more likely to be stopped from foreign matter being carried into it, which a less rapid stream could not have transported there.

In the case of a road whose surface was drained in the way just described, and whose surface was composed of proper materials in a compact state, very little water would find its way through to the substratum. With some descriptions of soil, however, it would be desirable to adopt means for maintaining the foundation of a road in a dry state; as, for instance, when the surface is a strong clay through which no water can percolate, or when the ground beneath the road is naturally of a soft, wet, or peaty nature. Under such circumstances it would be desirable to provide for its proper drainage by a species of under-drainage. As soon as the surface of the ground has been formed to the level intended for the reception of the road materials, trenches should be formed across the road, from 1 ft. to 18 in. in depth, and about 1 ft. wide at the bottom, the slides being sloped as shown in Fig. 6584. The distance at which these drains ought to be formed depends in a great measure on the nature of the soil. In the case of a strong clay soil, or one naturally very wet, there should be one about every 20 ft., and this distance might be increased as the ground became firmer or drier. In these trenches, a drain not less than 4 in. square internally should then be formed either of old bricks, drain-tiles, flat stones, or in any other mode used for under-drains, and the remainder of the trench should be filled with coarse stones, free from all clay or dirt, in the manner shown in Fig. 6584. Of course these drains must have a fall given them from the centre of the road into the ditches on either side. An inclination of 1 in 30 will be sufficient. When the road is level in the direction of its length, these drains should run straight across, but on those portions of the road which are inclined the drains should be formed as shown on the plan, Fig. 6585, somewhat in the form of a very flat V, the point being in the centre of the road, and the drains making an acute angle with the line of the road, in the direction in which it falls. The amount of this angle should not be greater than is shown in Fig. 6582.

6584.



6585.



When a road with footpaths is under-drained in the manner which we have just described, it will not be necessary to form drains from the side channel under the footpath into the ditch, as shown in Fig. 6582, but merely to carry up a little shaft, constructed in the same way as the drain, from the drain to the channel, covering the same with a small grating to prevent leaves or other substances, which might choke the drain, being carried into it. This method of forming the drains is shown at A, in Fig. 6583.

Foundation of Roads.—Before the foundation of a road is laid, the ground must be prepared for it, by levelling, draining, and forming it. If the subsoil be wet and elastic it must be brought to a dry, tolerably hard condition. It is of no use to lay good road materials upon a wet, bad substratum. Country roads, as distinguished from town roads and streets, are usually laid on the natural surface of the ground, in spite of the expensive and continual repairs necessitated thereby. In these cases, when the ground is wet, and as frequently occurs, undrained, deep ditches should be cut on each side of the line of road and cross drains laid underneath. If the ground is very springy or boggy, a layer of fagots, about 6 in. in depth, may be put down, before distributing the road materials. When the road is on an embankment the surface should be either rolled or punned, that is, beaten with heavy beetles, so as to ensure as great a degree of solidity as possible. The same mode of proceeding should be followed, even where it is intended to form either a paved or a concrete foundation, for too much care cannot be bestowed on that part of the road.

One mode of forming an artificial foundation for roads consists in forming a rough pavement on the top of the formation surface, which is afterwards covered by the road materials. Upon the level bed prepared for the road materials, a bottom course or layer of stones is set by hand, in form of a close firm pavement. The stones set in the middle of the road are 7 in. in depth; at 9 ft. from the centre, 5 in.; at 12 from the centre, 4 in.; and at 15 ft., 3 in. They are set on their broadest edge lengthwise across the road, and the breadth of the upper edge is not to exceed 4 in. in any case. All the irregularities of the upper part of the pavement are broken off by the hammer, and all the interstices filled with stone chips, firmly wedged or packed by hand, with a light hammer, so that when the whole pavement is finished, there shall be a convexity of 4 in. in the breadth of 15 ft. from the centre.

The foundations of roads exposed to a very heavy traffic, such as the streets of a large city, are generally now laid in concrete, whatever may be the nature of the road surface or materials subsequently put on. In this case the proportion of gravel to lime is that of 4 to 1. The concrete is made on the surface of the road, and great care taken, when the water is added, that every particle of the lime is properly slaked and saturated. The bed of concrete having been spread to the depth of 6 in. over the half breadth of the road, the surface is then covered over with 6 in. of good hard gravel or broken stone, and this depth is laid on in two courses, of 3 in. at a time, the first course being frequently laid on a few hours after the concrete has been placed on the road. The carriages, however, are not on any account allowed to pass over it until the concrete has become sufficiently hard and solid to carry the traffic without suffering the road material to sink and be pressed into the body of concrete. On the other hand, the covering of gravel is always laid on before the concrete has become quite hard, in order to admit of a more perfect binding and junction between the two beds, than would take place if the concrete were suffered to become hard before laying on the first covering. The beneficial effect arising from the practice of laying on the gravel exactly at the proper time is, that the lower stones, pressed by their own weight, and by those above

them, sink partially into the concrete, and thus remain fixed in a matrix, from which they cannot easily be dislodged.

Surface of Roads.—Metalling, or Macadam.—A macadamized or broken-stone road may be laid upon an artificial foundation, or may consist altogether of broken stone or road metal. The former was Telford's plan, the latter that of M'Adam. The stone or road metal should be hard, tough, and durable. The best materials are granite, trap-rock, or whinstone. Hard compact limestone may also be used, and gravel composed of flints; but all flints should be broken into angular pieces, as if for concrete. The stones are broken down by means of a hammer with a steel face, into smaller and smaller pieces, until at length they are reduced to pieces roughly approximating to a cubical shape, and not exceeding 6 oz. in weight; which, on an average, is the weight of a cube of stone of 1·6 in. in the side. M'Adam directed each road inspector to carry a small balance, so as to be able to test the weight of a few stones from each heap. Besides breaking all gravel into angular pieces, it should be screened, to clear it of earth.

The road metal, thus prepared, is to be evenly spread over the road with a shovel and rake, in three successive layers of between 3 and 4 in. deep, each layer being left to be partly consolidated by traffic before another is laid; and thus is formed a firm, compact bed of angular fragments of stone, about 10 in. thick, which is impervious to water, or nearly so, and which soon acquires a smooth surface. According to M'Adam, 10 in. is the greatest thickness of metal required for any road, from 5 to 9 in. being often sufficient. His practice was to lay the metal simply on the natural ground, with no preparation except levelling inequalities and digging drains.

In order to make the traffic on a broken-stone road easier when it is first laid, a layer of sand and gravel, called blinding, is sometimes spread over it, but this practice is a bad one, for the sand and gravel work their way between the fragments of stone, and prevent their ever forming so compact a mass as they ought to do.

Paved Roads.—Stone.—In towns and other places where there is a constant and heavy traffic, the streets are generally paved with stone. Cubes or setts of granite, from 3 to 6 in. wide, 7 to 20 in. long, and from 6 to 9 in. deep, are laid closely side by side upon a substratum of concrete or broken stone, compressed into hard macadam, and the surface is grouted with lime and sand. A depth of 9 in. is the maximum, even for the heaviest traffic in the streets of London, blocks 7 in. being sufficient for ordinary service, and $4\frac{1}{2}$ in. the minimum anywhere. In London a pavement of new Aberdeen granite, 3 in. wide and 9 in. deep, under a heavy and concentrated traffic, such as that of Cheapside, must be renovated, and the stones redressed and relaid, every five or six years, but on ordinary roads granite pavement, if properly laid in the first instance, will last from ten to thirty years. When laid upon bridges there should be a concrete substratum, not less than 6 in. thick, between the platform and the stone. A heavy road material of this kind is best adapted for short spans, for cast-iron arched bridges, and for other situations where the dead load may with advantage compare largely to the moving load.

Paved Roads.—Wood.—The ordinary method of forming a roadway for permanent use is by laying blocks from 4 to 7 in. deep, close together, with the grain of the wood vertical. Oak or other hard timber was formerly considered the best, but it has been found that fir, although not so hard, is better, and that its longer fibre renders it more durable than oak, and not so slippery.

As under constant traffic the blocks will sometimes become loose, different plans have been tried for holding them together. Octagonal or hexagonal blocks have been fitted together so as to give homogeneity to the whole, and prevent lateral movement. The same result is sought by priming or mortising the blocks together, and many ingenious and complicated methods of this kind have been attempted. In a large area the density of the blocks will vary, or the ballast or concrete below may not be equally solid at all points, and some of the blocks, under the pressure of a heavy load, will sink down and make an uneven roadway. To prevent this, the plan has been adopted of making the pieces of the shape in Fig. 6586, so that the pressure upon any one piece is to some extent borne by the adjoining piece. A considerable improvement on this plan is effected by making the blocks of the shapes in Fig. 6587, so as effectually to unite them against the downward pressure of a load.

By the methods above described the blocks are laid close together; and as, under certain circumstances, a wood pavement may become slippery, it is by some engineers considered that a better foot-hold for horses may be obtained by leaving a gap between the blocks. Figs. 6588, 6589, illustrate one of these methods, the blocks being laid $\frac{3}{4}$ in. apart, and the spaces between them filled in with cement or mortar. But cement or mortar once disintegrated, as in this case is likely, will not again unite, and for cohesive purposes becomes useless.

6586.

6587.

6588.

6589.

A pavement which seems to unite the supposed advantages of those in Figs. 6586 to 6589 has been used with some success in America, and is now, 1872, on trial in London and other European cities.

The arrangement of the blocks, and the process of laying them, may be thus described;—Planks $\frac{3}{4}$ in. thick, having been dipped in tar, are laid across the road upon a bed of concrete, or upon previously existing hard macadam, and a second layer of similar planks is laid longitudinally. Dantzic fir blocks 9 in. long, 3 in. wide, and 6 in. deep, are then laid across the street upon the planks, and a long strip of wood, $\frac{7}{8}$ in. square, is nailed to the bottom of the blocks and to the planking. This strip of wood forms a distance-piece, separating one row of blocks from another, and as the parallel rows are laid, there are, of course, gaps $\frac{7}{8}$ in. wide between each. Into these gaps or spaces small grit or gravel, without sand, is inserted, and driven in by blows from a mallet; and liquid tar is

poured upon the gravel so as to soak into it. By this plan the pressure upon any one block is divided by the planks over a considerable area of the substratum, but the planks are an obstruction if trenches or small openings in the roadway have to be made for repairs of gas-pipes; or any works laid underneath.

With careful treatment a wood pavement may be made to last a long time in a cold or temperate climate. When first laid, the surface should be well tarred and sprinkled with fine gravel; and this should be repeated occasionally, and at any time during a frost, to prevent slipping. The gravel will be forced into the wood, and will harden and preserve it. The accumulation of mud should be prevented.

Asphalted Roads.—Asphaltum is one of the varieties of bitumen found in many parts of the world, and generally in the nature of rock. The asphalte used is of two kinds, the compressed and the liquid or mastic asphalte. The former is in its natural condition of mineral rock, and made into powder. This powder, having been heated, is laid upon concrete, and is compressed by heated irons into a homogeneous mass. The liquid or mastic is a mixture of asphalte with mineral tar and small grit, from gravel or shingle, and is applied as a hot paste. It is in this condition also that other asphaltes are applied.

In London, for the heaviest traffic, a stratum of concrete, 6 in. to 9 in. thick below the asphalte, has been adopted, but for less severe service it would not be necessary to use more than 5 in. of concrete, which thickness, for instance, on the iron platform of a bridge would suffice. The asphalte itself is laid 2½ in. thick for constant heavy traffic, and 1½ to 2 in. for ordinary traffic. On side paths for foot-passengers, asphalte ½ in. thick laid on 3 in. or 4 in. of concrete is sufficient.

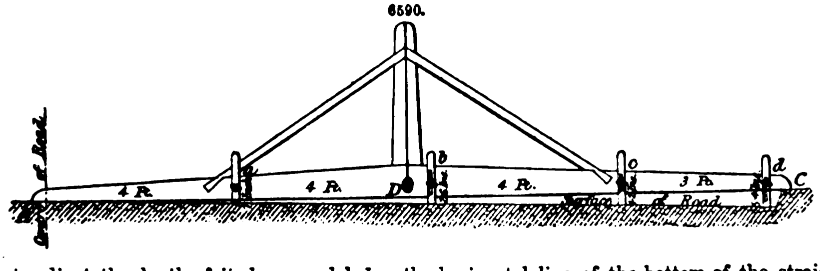
The qualities which recommend asphalte are, the smoothness of surface, which renders traction easy; the diminution of noise; and, for bridges, its moderate weight as compared with stone. The headway below a bridge may be increased, or the gradient rendered easier, by a reduction in the thickness of the road material. There is no doubt that the thickness of the asphalte becomes considerably reduced when in use, but it is not yet clearly known whether this is owing to attrition only, or in some measure to the compression which is claimed for it by its advocates. On a level surface, in dry or wet weather, asphalte, if kept clean, is not more slippery than stone; but for steep ascents traction would be difficult, and if the gradient were such as to render brakes or drags necessary, the grinding action of the locked wheels would be injurious to the asphalte. In the City of London, 1 in 60 is the steepest gradient for which asphalte is permitted. Asphalte cannot be successfully laid or repaired in frosty weather. It has been proved to be free from danger by fire.

Maintaining and Repairing Roads.—Too great attention cannot be bestowed upon keeping the road surface from an accumulation of mud, and even of dust. It should be constantly cleaned by scraping and sweeping. The repairs should be daily made by adding fresh material upon all points where hollows or ruts commence to form. It is recommended by some that when fresh material is added, the surface on which it is spread should be broken with a pick to the depth of half an inch to an inch, and the fresh material be well settled by ramming, a small quantity of clean sand being added to make the stone pack better. When not daily repaired by persons whose sole business it is to keep the road in good order, general repairs should be made in the months of October and April, by removing all accumulations of mud, cleaning out the side channels and other drains, and adding fresh material where requisite.

The importance of keeping the road surface at all times free from an accumulation of mud and dust, and of preserving the surface in a uniform state of evenness, by the daily addition of fresh material wherever the wear is sufficient to call for it, cannot be too strongly insisted upon. Without this constant supervision, the best-constructed road will, in a short time, be unfit for travel, and with it, the weakest may at all times be kept in a tolerably fair state.

We shall next proceed to a brief description of the tools or implements employed in the construction and repair of roads. The most important of these is the level used for forming the true transverse section of the road. It consists, Fig. 6590, of a horizontal straight-edge or bar A C, having in the centre of its length a plummet B D, for ascertaining when the straight-edge is horizontal. A line is drawn near the end A of the bar, and at every 4 ft. from this line a gauge *a b c d* is fixed in a dovetailed groove, in such a way as to be capable of being moved up or down,

6590.



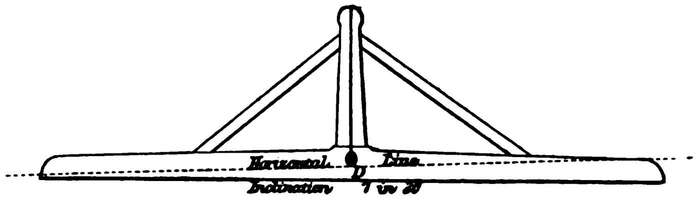
so as to adjust the depth of its lower end below the horizontal line of the bottom of the straight-edge; and there are thumb-screws, one of which is shown on an enlarged scale in Fig. 6592, passing through each gauge, by tightening which the gauge can be fixed when so adjusted. When the bottoms of the gauges *a*, *b*, *c*, and *d*, have been adjusted as in Fig. 6590, they will coincide with the surface recommended to be given to a road 30 ft. in width, as in Fig. 6582; and in order to ascertain whether the surface of any existing road is constructed to the proper inclination and form, it is only requisite to apply the level, which, when placed perfectly horizontal, by means of the plummet B D, should rest upon the road at the lower extremity of each of the gauges *a*, *b*, *c*, and *d*. For forming

the sides of roads of greater width than 30 ft., it would be convenient to have a level constructed in the manner shown in Fig. 6591, in which the A B is a straight-edge about 15 ft. long, having in the centre of its length a plummet C D, so adjusted that when hanging truly in its place, the lower side of the straight-edge should be inclined from a horizontal line at the rate of 1 in 30.

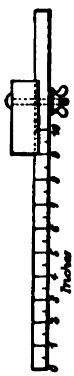
Fig. 6596 is the pick used for lifting the surface of roads. The bent iron head *a b* should weigh about 10 lbs., having a large eye in the centre *c*, in which is fitted the handle, which should be of ash, rather more than 2 ft. in length; one extremity, *a*, should be formed like the end of a chisel, while the other, *b*, should terminate in a blunt point. Both ends should be tipped with steel.

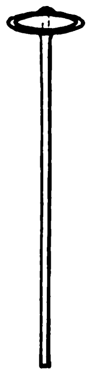
The most useful form of shovel for road purposes is shown in Fig. 3841, p. 1834. The blade should be somewhat pointed, and the handle bent, so as to enable the person using it to bring the blade flat upon the surface of the road without excessive stooping.

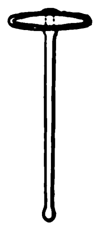
6591.



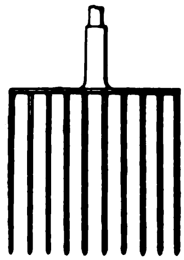
6592. 6593. 6594. 6595.

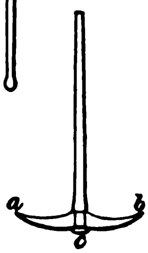






6597.





6596.

The ordinary wheelbarrows are of ash or elm, with cast-iron wheels; but it would be an advantage if wheelbarrows for road purposes were made of wrought iron, which would combine strength and durability with lightness. Of whatever material, however, they are constructed, they should not exceed 9 in. in depth, and their sides should be splayed with a slope of 2 to 1. It would be also very desirable to have hooks placed on their sides to receive a shovel and pick.

The screens, or sieves, employed for separating the coarse gravel from the hoggin or small gravel, consist of iron wires or slender rods, placed at equal distances apart, and fixed in a frame of wood, the sides of which are raised about 5 in. above the plane of the wires. In the screens the frames are rectangular, about 5 ft. 6 in. in height and 3 ft. wide, and the wires are stretched in the direction of its length at distances varying from ¼ in. to 1¼ in., according to the size of the stone required; and these wires are kept in place by others crossing them at intervals of 5 or 6 in. When used, they are placed so that the plane of the wires is inclined about 30° from the upright, and the gravel to be screened being dashed or thrown forcibly against them; the finer particles pass through and fall on the farther side of the screen, while the large stones roll down its surface and fall on the nearest side. The sieves are somewhat different in form, the frame being circular, forming a cylinder about 6 in. in depth and 20 in. in diameter, the wires being placed either as we have already described, or equally close in both directions, and forming a kind of bottom to the cylinder. The sieve is held horizontally by one man, while the other throws into it a shovelful of gravel. Upon shaking the sieve, the fine hoggin falls through, leaving the stones in the sieve, which are then thrown by the man into anything which may be placed to receive them. The latter is generally the best and cheapest mode of screening gravel.

The hammers employed for breaking stones are of two sizes, Figs. 6593, 6594. The handles should be of straight-grained ash, and the iron heads of the form shown in the drawings; the faces spherical, and case-hardened, or steeled. Fig. 6595 represents the ring to be used for testing the size of the broken stones. Its internal diameter is 2¼ in., and the largest stones should be able to be passed through the ring in every direction.

Fig. 6597 represents a pronged fork, to be used instead of a shovel for taking up the stones to throw upon the road. The advantages attending its use are, that a man can take up the stones much quicker and easier than with a shovel, and free from all dirt and extraneous matter which, in the case of broken angular stones, is of importance.

The rakes, which should be employed in filling in ruts and hollow places in the surface of roads, should be formed with prongs between 2 in. and 3 in. in length, fixed, at the distance of ¾ in. apart, into a wooden head about 11 in. in length. Their handles should be formed of ash, and should be about 6 ft. in length. Scrapers are indispensable for preserving roads in a proper state and free from mud. They are usually constructed of wood shod with wrought iron, but it is much better to make them entirely of iron. They should be 6 in. in depth, and about 18 in. in length, and slightly curved at each extremity to prevent the escape of mud at each side.

Scraping machines are very generally employed, by means of which the surface of a road may be scraped much more regularly and quickly than with the old scrapers. They consist of a number of iron scrapers, attached to a frame mounted on wheels, which are so placed that, when the body of the machine is somewhat raised, the wheels are lifted from the ground, and the whole weight of the machine is thrown upon the scrapers, which, upon the machine being drawn across the road, scrape all the mud from its surface, and carry it to the sides.

A machine has also been invented by Whitworth for sweeping up the mud from the roads and carrying it away at once. It consists of a species of endless broom, passing round rollers attached to a mud cart, and so connected by cogged wheels with the wheels of the cart, that when the latter is drawn forwards, the broom is caused to revolve, and sweeps the mud from the surface of the road up an inclined plane into the cart. The machine is drawn by one horse, and by its aid the roads are swept much more rapidly and better than by the old system of scraping.

Fences.—Where fences are indispensable they should be kept as low as possible, and thrown as far as is possible from the sides of the road. Where the road has a deep ditch on either side, it then becomes necessary, to prevent accidents, that the fence should be placed between the road and the ditch. In all other situations, the fence should be placed on the field side of the ditch, for the double reason, that in so doing the surface drainage of the road into the side ditches is less interfered with, and that the road is then not so much sheltered by the fence itself. The different descriptions of fence which may be employed are very various, and those which answer in the case of railways will do equally well for roads.

Rolling Roads.—The importance of rolling roads, either newly constructed or when subjected to extensive repairs, is now duly appreciated, and a road may be put at once into good working condition, and a considerable expense eventually saved, by thorough systematic rolling. No road ought to be considered as made until that operation shall be completely effected.

There are certain considerations which may serve as guides to arrive at first conclusions with regard to rolling roads, which in London and other large cities is usually done by steam rollers.

A roller should not be too heavy in proportion to its bearing surface, or, instead of binding the material in the position and form laid down and desired, it will press it more or less into the substratum. Much of the material will thus become useless, and it will be very troublesome to obtain the necessary resistance for consolidation. It must not be too light, or the effect will be too small ever to gain the object fully, or at any rate without an extent of operation that would be very costly or inconvenient. From recorded trials, there is reason to believe that a road roller should not be lighter than 28 cwt. for every 12 in. lineal bearing on the road; that is, if 4 ft. wide, that it should weigh 5 tons 12 cwt.; if 3 ft. 4 tons 4 cwt., and so on in proportion. It should only be applied to the upper surface of the road.

A roller somewhat heavier than 28 cwt. a foot would be more effective, but it is better after that limit, to gain the object rather by adding to the number of times that the surface is passed over, than incur the inconveniences of the heavier machinery. For effect, the wider a roller can be the better, because the operation will be more quickly performed, and because, in proportion as it is narrow, will there be a tendency to force the broken stone laterally from under its action. But, as the weight must be in proportion to its bearing surface, the width must be limited to a degree that will prevent that weight being too unwieldy. A very narrow roller might also have a tendency to overturn.

On the other hand, one that is very wide may take up too much room, if the road is open to traffic during the time of its use.

It is absolutely necessary to apply some gravel, or other sharp, gritty, fine stuff on the surface, during the operation, without which it will not be thoroughly bound. The consolidation commences with the lower part, which is the first to get fixed and arranged, and when, after about six turns over the whole, the upper layers have become tolerably firm and well bedded, some sand or stone-dust, or, what is best of all, sharp gravel, may be lightly sprinkled over it by degrees at every successive rolling, solely for the purpose of filling up the interstices of the broken stone, and not to cover it. About 3 cub. yds. in 100 sq. yds., equal to about 1 in. in thickness, spread over the whole surface, will be required. It is essential that this small stuff be not applied earlier, or it will get to the lower strata, and not only be wasted, but injurious. The object is that it should penetrate for 2 or 3 in. only, to help to bind the surface. Provided the upper interstices are filled, the less gravel used the better. It should be applied by degrees after each of the three or four last successive passages of the roller, and then only over the places where there are open joints. After the work, if well done, is completed, it is stated that such is the effect that the upper crust may be raised in cakes of 6 or 7 sq. ft. at a time, which could never be done without the gravel. The effect may be improved also by having the upper inch or two of stone finer than the rest, to pass through a ring of 1¼ in. or 1½ in. This work should be done in wet weather, or the material will require to be watered artificially, as is done in practice.

See Asphalte. Permanent Way. Railway Engineering.

Works relating to the subject;—Gautier (H.), 'Traité des Chemins,' 8vo, Paris, 1721. Delaistre (J. R.), 'Dictionnaire des Ponts et Chaussées,' 3 vols. 8vo; atlas 4to, Paris, 1812. Edgeworth (R. E.), 'On Roads and Carriages,' 8vo. 1817. M'Adam (J. L.), 'On Roads,' 8vo, 1821. Cordier (J.), 'Essais sur la Construction des Routes,' 2 vols. 8vo; atlas in fol., Paris, 1823–28. Parnell (Sir H.), 'A Treatise on Roads,' 8vo, 1838. Leahy (E.), 'On Making and Repairing Roads,' 12mo, 1844. Polonceau (A. R.), 'Notice sur l'Amélioration des Routes,' 4to, Paris, 1844. 'Programmes

de l'École des Ponts et Chaussées,' 10 vols. 4to, 1848–1872. Burgoyne (Sir J. F.), 'Art of Constructing and Repairing Common Roads,' 12mo, 1861. Paget (F. A.), 'On the Economy of Road Maintenance,' 8vo, 1870. Gillespie (W. M.), 'Principles and Practice of Road Making,' 8vo, New York, 1872. See also 'Life of Thomas Telford,' C.E., 4to, and fol.; and Papers in the 'Minutes of the Institution of Civil Engineers,' the 'Annales des Ponts et Chaussées,' and the 'Professional Papers on Indian Engineering.'

ROCK-SHAFT. Fr., *Arbre oscillant;* Ger., *Oscillirende welle;* Ital., *Albero oscillante;* Span., *Arbol oscilante.*

Rock-shaft is a name applied to any shaft that oscillates on its journals, instead of revolving: more strictly, a vibrating shaft for modifying motion in the valve-gear of a steam-engine. It is called also *rocker* and *rocking shaft.*

ROLLING MILL. Fr., *Laminoir;* Ger., *Walzwerk;* Ital., *Laminatoio;* Span., *Laminador.*
See Iron.

ROOFS. Fr., *Toits;* Ger., *Dächer;* Ital., *Tetti;* Span., *Tejados.*

The subject of roofs is one which is closely allied to that of bridges, especially since the introduction of iron as a constructive material, and its increasing employment by engineers and architects in both these descriptions of structures. A roof is, in fact, nothing else than a bridge, which has comparatively a light load to support, and one, moreover, which is of a less variable and impactive character. The greatest static load which can come upon a roof is when it is covered with snow, and the greatest dynamical, when one half of it is exposed to the action of a violent storm, or wind pressure. The former is provided for by making the roof strong enough in every part to bear this maximum load, and the latter by a proper arrangement of bracing and wind-ties. The greatest strain to which a roof can be exposed, whether statical or dynamical, is trifling in comparison with that which would attend a bridge of equal span, intended for either heavy road or locomotive traffic. In some few instances, roofs and bridges have been built almost identical in shape, and in the examples of iron roofs and bridges there is frequently a general resemblance both in principle and form. The different purposes for which the two structures are intended, and the different conditions under which they are placed, otherwise than when the mere question of strain is concerned, prevent that close resemblance being universally obtained. Practical considerations also will always, and particularly in large examples, tend to maintain that diversity of arrangement which experience has shown to be not only unavoidable but absolutely necessary under the circumstances.

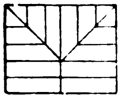
Classification of Roofs.—Roofs can be divided into two classes, which will comprise all roof structures, namely, those in which the pressure upon the supports is at an angle outwards with the vertical, and those in which it is in a vertical direction only. Accordingly roofs without a horizontal thrust are complete in themselves, or self-contained, and those with a horizontal thrust are incomplete, and their stability depends on that of the abutments. To these, however, must be added a third class, which, taken separately, have a horizontal thrust, but which, by being arranged upon a circular, elliptical, or polygonal base, and inclined towards a common centre, can be made dependent upon each other, and independent of abutments, by connecting them at their springing by a tie, which, as it joins all the principals at their springing, is in plan a polygon. Such roofs are called domed or curved roofs.

Designing Roofs.—Before an engineer can undertake to design and prepare the necessary drawings for either a timber or an iron roof, it is indispensable that he be supplied with some data, however slight, upon which to proceed. In general he will require the following, in addition to the ground plan and proposed height of the structure. 1. The description of support provided for the roof, so that he may determine whether the design shall be that of a simple trussed roof or of an arched roof, which would exert a horizontal thrust against the walls or columns upon which it might be carried. 2. The purpose for which the building is intended. Beyond a width of about 40 ft., the question arises whether the roof shall be made in one or more spans, and as the cost may in some cases be considerably diminished by having the roof supported at intervals between the walls, so reducing the width of any one span, it is necessary to know if intermediate columns or walls, so placed, will prove an obstruction. 3. It must be known whether the building is to be open at the sides and ends, or to be enclosed, and if the latter, whether by walls, or by iron screens, or glass. 4. As it is sometimes cheaper and better to make a roof hipped, Figs. 6598, 6599, than gabled, Figs. 6600, 6601, any reason or preference for or against either plan should be given. 5. The nature of the climate should be stated with reference to the following points:—The ventilating arrangements which may be needed; the kind of roof covering most suitable; the strength of the roof for resisting heavy winds or hurricanes; the nature and amount of light required, and the gutters and rain-pipes necessary. Any local drains to which the rain-water must be conveyed should be indicated, so that the vertical pipes or water columns may be arranged accordingly. 6. The designer should be informed whether the structure is to have any ornamental character, or whether cheapness is the primary consideration. 7. If there are difficulties in the way of transporting materials to the site, they should be stated, so that, if necessary, the roof may be made in pieces of moderate size and weight. It is useful to know whether skilled labourers can be obtained for erecting the roof, so that if it is difficult to procure them, the design may be contrived with special reference to facility of erection. Information also should be afforded as to what materials, such as brick, stone, or timber, can be obtained near the site, and, if possible, at what prices. It may be stated as a general rule, that roofs and buildings, especially when of iron, should have their parts equally divided. A hipped roof should consist of regular squares, in accordance with which the columns, principals, and purlins can be arranged. Facilities for repetition and the economical disposition of material are afforded by making the divisions of the sides and ends corresponding. Thus a plan arranged as in Fig. 6602, with the side

6598. 6599. 6600. 6601.

and end spaces all equal, is better than an irregularly shaped plan. Where an irregular plot of ground has to be covered, it is better to confine the irregularity to as few points as possible, and to let the greater part of the structure be composed of rectangular or other uniform figures, than to provide for the irregularities by altering the dimensions of parts gradually throughout the whole building.

6602.



Pitch of Roofs.—The pitch of a roof, or the angle which its inclined side forms with the horizon, is varied according to the climate and the nature of the covering. The inhabitants of cold countries make their roofs very high, while those of warm countries, where it seldom rains or snows, make their roofs nearly flat, but the practice even in the same climate has varied considerably. Low roofs require large slates and the utmost care in execution. They are cheaper than high ones, since they require timbers of less length and of smaller scantling. Formerly the roofs were made very high, perhaps with the notion that the snow would slide off easier, but where there are parapets a high roof is attended with bad effects, as the snow slips down and stops the gutters, and an overflow of water is the consequence. Besides, the water in heavy rains descends with such velocity that the pipes cannot convey it away soon enough to prevent the gutters overflowing. In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it is supposed to have been with a view of lessening their height that the Mansard or curb roof was invented. The quantity of room lost by a curb roof, the difficulty of freeing the gutters from snow, and the ungraceful effect of the roof itself, are objections that are not compensated by the small difference of the expense between it and a common roof, especially now that experience has proved that roofs may be made much less in height than our ancestors were in the habit of making them.

The height of timber roofs at the present time is very rarely more than one-third of the span, and should never be less than one-sixth. The usual pitch for slates is when the height equals one-fourth of the span, or when the angle with the horizon is 26½°. Near the sea, or in very exposed situations, the height of the roof should be one-third of the span, for if less, the rain and snow will be driven under the slates by the wind.

The same conditions with respect to the pitch prevail in the case of iron roofs when they are of the trussed form. Greater latitude is allowed when the arch forms are used, as will be seen from the examples selected for illustration.

Loads on Roofs.—Statical or Permanent Load.—The load on a roof is of a double character, and consists of the statical or permanent load, and the dynamical or accidental load. The static load is composed of the weight of the framework which includes the principals, primary and secondary, and the purlins, and of the weight of the covering together with the louvres, glazing, and any ornamental additions.

Dynamical or Accidental Load.—The accidental load consists of snow and the pressure of the wind. An allowance of about 6 lbs. a square foot is sufficient in England, but a maximum of 20 lbs. has been allowed in other countries. The estimate of the allowance for wind pressure may be put at about 30 lbs. a square foot. Tredgold estimated the total accidental load on roofs at 40 lbs. a square foot of surface covered, or say 35 lbs. for wind and 5 lbs. for snow pressure, and the largest roofs are generally constructed for a uniformly distributed vertical load of this amount. When, however, the great Lime Street roof at Liverpool of 153 ft. span was erected, it was immediately seen that a uniformly distributed load was not the worst casualty to which it might be subjected. Locke, therefore, in spite of a protest from its designer, required that a rib should be tested with a load of 40 lbs. a square foot hung on one half the roof, the other being unloaded, thus imitating, as nearly as was possible with a vertical load, the effect of the wind pressure acting broadside on. A rib of the great Birmingham roof was similarly tested, first with 40 lbs. a square foot uniformly distributed over the whole roof, and next with a similar load on half the roof only. In these cases the testing load represented the snow pressure, the wind pressure, and the weight of the permanent roof covering.

The ordinary force of gales amounts to from 20 to 25 lbs. a square foot on a surface perpendicular to their direction. More rarely, higher pressures are registered, ranging from 33½ lbs. to as much as 55 lbs.

If the maximum pressure of the wind is assumed at 40 lbs., it will be sufficient. On the inclined surface of a roof the pressure will be much less than this, the law of the variation of the pressure with the inclination being known with tolerable accuracy from the experiments of Hutton. Let P be the intensity of the wind pressure in lbs. the square foot, on a surface perpendicularly opposed to it; θ the inclination of any plane surface to the wind's direction. Then the intensity of the pressure normal to the surface will be, $P n = P \sin. \theta^{\,1 \cdot 84 \cos. \theta - 1}$. The component of that pressure, parallel to the wind's direction, will have the intensity, $P h = P \sin. \theta^{\,1 \cdot 84 \cos. \theta}$. The component perpendicular to the wind's direction, the intensity, $P v = P \cot. \theta \sin. \theta^{\,1 \cdot 84 \cos. \theta}$.

That is, if the wind blow horizontally $P h$ is the horizontal and $P v$ the vertical component of the pressure on the roof. Putting $P = 40$, we get the following values of the normal pressure and its components, for various inclinations of the roof surface to the direction of the wind;—

LBS. A SQUARE FOOT OF SURFACE.

Angle of Roof.	P n.	P v.	P h.	Angle of Roof.	P n.	P v.	P h.
°				°			
5	5·0	4·9	0·4	50	38·1	24·5	29·2
10	9·7	9·6	1·7	60	40·0	20·0	34·0
20	18·1	17·0	6·2	70	41·0	14·0	38·5
30	26·4	22·8	13·2	80	40·4	7·0	39·8
40	33·3	25·5	21·4	..	40·0	0·0	40·0

Now whether a roof is exposed to a vertical wind-pressure of 35 lbs. a square foot, as in Tredgold's assumption, or not, it is certain that it will be exposed to the pressure of winds blowing horizontally. If, therefore, according to the common practice, the roof is designed to resist a uniform vertical pressure of 40 lbs. a square foot, plus the weight of the framing, it is at least equally necessary to examine whether it will resist the partial normal pressures given in the previous Table, which, in many cases, will produce a much greater distorting effect, and an entirely different distribution of stress on the bracing. It is difficult to fix the limits of the probable variation of the direction of the wind relatively to the roof, but if we suppose that in eddying gusts it may strike the roof, in any direction between the horizontal and vertical, then the maximum stress on any given member will be found in one or other of the three following cases;—

1. Wind blowing horizontally, which is the most ordinary condition of loading.
2. Wind normal to one side of the roof surface.
3. Wind vertical, which may possibly happen as a momentary condition, but which is certainly the least probable of possible modes of loading. The ordinary assumption, that the roof is subject to uniform vertical loads only, supposes the wind vertical, and neglects the horizontal component of the pressure, which will exist even in that case.

In the two former cases the loading due to the wind is unsymmetrically and unequally distributed. In the third case the loading is uniform in straight-raftered roofs, and symmetrical in arched roofs.

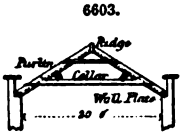
Timber Roofs.—Roofs of this material have, similarly to bridges, been greatly superseded by those of iron, particularly when of large dimensions. For small spans, timber roofs will always be employed, so long as the material is procurable. For spans of moderate dimensions, they are still very frequently used. They are less heavily strained than bridges, and are, moreover, if well built, better secured from the effects of the weather, and are consequently more durable. As a rule timber roofs are built a great deal too heavy, a consequence probably of a somewhat too servile adherence to old types of construction, in which weight was synonymous with strength. The most economical roof, and the one also which will best fulfil the conditions of proportion and efficiency among its relative parts, will invariably be that which contains the minimum amount of material, provided the structure be scientifically designed. The principal point of difference to be noticed in the comparison of the ancient and modern roofs is, that in the former the abutments in the form of buttresses were employed to take the thrust at the feet of the rafter, while in the majority of the latter, a tie, horizontal or inclined, is used instead.

Of timber roofs there are numerous varieties, the best known of which and those most frequently employed we shall briefly describe and illustrate.

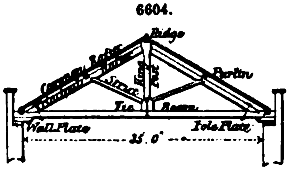
Fig. 6603 is a very simple truss, in which the tie is above the bottom of the feet of the principals, which is often done in small roofs for the sake of obtaining height. The tie in this case is called a collar. The feet of both common and principal rafters rest on a wall-plate. The purlins rest on the collar, and the common rafters abut against a ridge running along the top of the roof. This kind of truss is only suited to very small spans, as there is a cross strain on that part of the principals below the collar, which is rendered harmless in a small span by the extra strength of the principals, but which in a large one would be very likely to thrust out the walls.

In roofs of larger span the tie-beam is placed below the feet of the principals, which are tenoned into, and bolted to it. To keep the beam from sagging, or bending by its own weight, it is suspended from the head of the principals by a king-post of wood or iron.

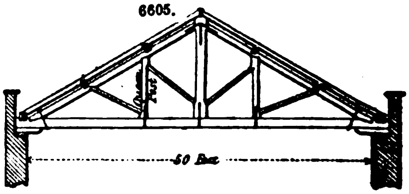
6603.



6604.



6605.

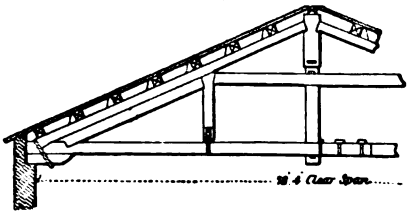


The lower part of the king-post affords support for the struts supporting the principals immediately under the purlins, so that no cross strain is exerted on any of the timbers in the truss, but they all act in the direction of their length, the principals and struts being subjected to compression, and the king-post and tie-beam to tension. Fig. 6604 is a sketch of a king-truss. The common rafters abut on a pole-plate, the tie-beams resting either on a continuous plate, or on short bed-plates of wood or stone. Where the span is considerable, the tie-beam is supported at additional points by suspension pieces called queen-posts, Fig. 6605, from the bottom of which spring additional struts. By extending this principle, we might construct a roof of any span, were it not that a practical limit is imposed by the nature of the materials. Sometimes roofs are constructed without king-posts, the queen-posts being kept apart by a straining piece, as in Fig. 6606, which shows the design of the old roof of the church of St. Paul, outside the walls, at Rome. This truss is interesting from its early date, having been erected about 400 years ago and since destroyed. The trusses are in pairs, a king-post being keyed in between each pair to support the tie-beams in the centre.

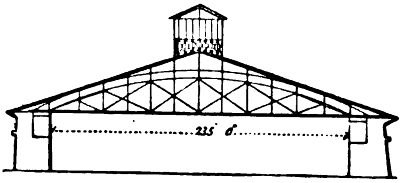
The largest timber roof ever designed in one span was intended for the Imperial Riding House at Moscow, but was never built. The span was 235 ft., and the elevation is shown Fig. 6607. The principal feature in this roof was an arched beam, the ends of which were kept from spreading by a tie-beam, the two being firmly connected by suspension pieces and diagonal braces. The arched beam, Fig. 6608, is formed of three thicknesses of timber, notched out to prevent their sliding on each other. This method is objectionable on account of the danger of the splitting of the timber under a considerable strain.

When the span of a timber roof exceeds 60 ft. the truss, Fig. 6609, may be employed to advantage. One half is shown in the figure with a queen-post, and the other with the similar member acting

6606.

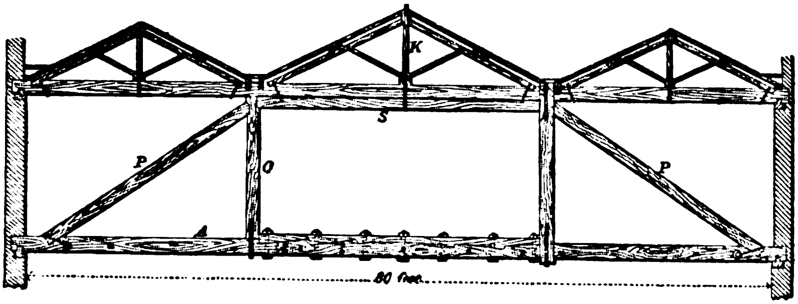


6607.

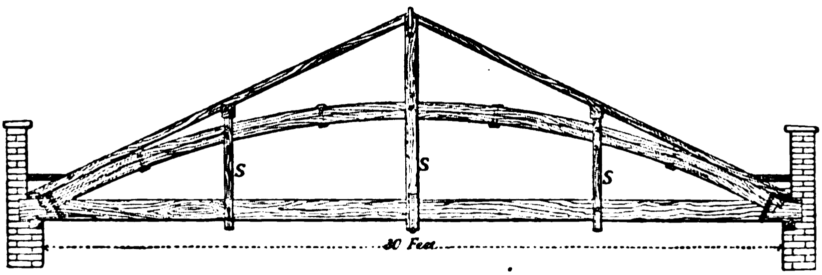


6608.

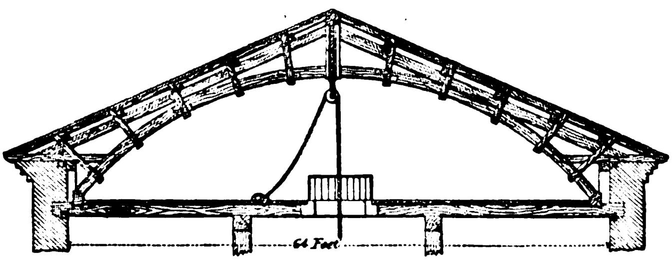
6609.



6610.



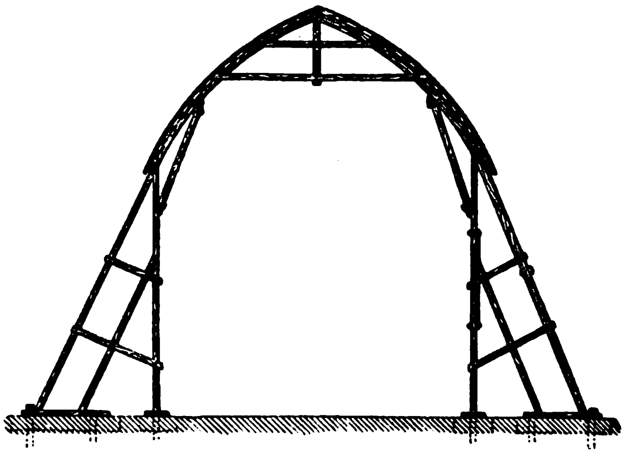
6611.



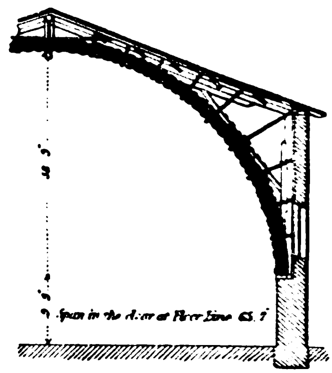
as a suspended tie. The middle part of the longitudinal tie-beam is constructed as a girder. Fig. 6610 is a roof in which the ribs are all in one piece, and bent in the same manner used for ship timbers. The rise or versed sine of the ribs is one-half that of the roof, and the suspending pieces are notched in pairs, and bolted and strapped together. The noticeable good points in this roof are the small number of joints in the truss, the number of points at which it can support the tie-beam, and dispensing with the shrinkage which attends the use of king and queen posts. Fig. 6611 is a roof designed for a provision store at Helder, in Holland. The rafters were supported by a solid arched rib formed in five lengths, connected by scarfs. The length of the store for which this roof was designed is nearly 320 ft., and the width 64 ft. The ribs were spaced 16 ft. apart from centre to centre, and between each pair were six rafters, which supported the roof. The floor-beams were supported by posts, which were indispensable in consequence of the great span, 64 ft. An architect designing a roof on this principle at the present time would avail himself of the

use of iron to a greater extent than appears in this design. Fig. 6612 is a design taken from Emy's and Demanet's works. It is particularly adapted for a ship-builder's shed, and has been used for covering locomotive sheds. Unless the sides are well covered in, this description of roof is very liable to be blown off by the wind getting in underneath. It would also require very strong holding-down bolts, let into a good block of concrete or large deep bed-stones as in the figure. About thirty years ago a portion of a roof of this kind, erected at Chatham, was blown clean away, for a distance of 60 or 70 ft.

6612.



6613.



About the sixteenth century, Philibert de Lorme, a celebrated French architect, introduced a description of roofs and domes with a series of arched timber ribs in place of trusses, these ribs being formed of planks in short lengths, placed edgewise, and bolted together in thicknesses, breaking joints.

There are some great disadvantages connected with this system. The labour is great as compared with roofs of similar span of the ordinary construction, and, as the chief strength of the rib depends upon the lateral cohesion of the fibres of the wood, it is necessary to provide a large amount of surplus strength. But Emy proposed an improvement on the system which was precisely the laminated arched rib which has continued in use to the present day.

This design was put into execution in the erection of a large roof 65 ft. span at Marac, near Bayonne, Fig. 6613. The ribs in this roof are formed of planks bent round on templets to the proper curve, and kept from separating by iron straps, and also by the radiating struts which are in pairs, notched out so as to clip the rib between them.

The principle of the roof is exceedingly good. The principals, wall-posts, and arched rib form two triangles, firmly braced together, and exerting no thrust on the walls, and the weight of the whole roof being thrown on the walls at the feet of the ribs, and not at the pole-plate, the walls are not tried by the action of a heavy roof, and the consequent saving in masonry is very great.

The great difference in principle between the arched rib of Philibert de Lorme, and the laminated rib of Emy, is, that in the latter the direction of the fibre of the wood coincides with the curvature of the rib, and, as a consequence of this, the joints are much fewer. The rib possesses considerable elasticity, so as slightly to yield rather than break under any violent strain, and, from the manner in which the planks are bolted together, it is impossible for the rib to give way, unless the force applied be sufficient to crush the fibres.

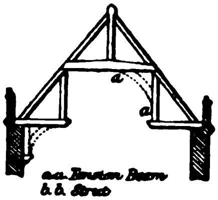
Gothic Roofs.—The open timber roofs of the middle ages come, for the majority, under the second class, namely, those which exert more or less thrust upon the walls, although there are many fine examples in which this is not the case.

The high-pitched roofs of the large halls of the fifteenth and sixteenth centuries, for the most part, are trussed in a very perfect manner, so as to exert no thrust upon the walls; although, in some instances, as at Westminster Hall, they depend upon the latter for support.

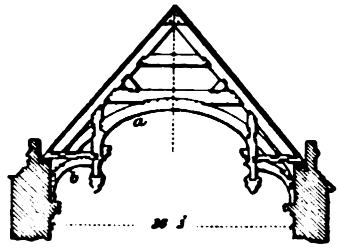
The general design of these roofs is shown in Figs. 6614, 6615. The essential parts of each truss are a pair of principals connected by a collar or wind-beam, and two hammer-beams, with queen-posts over them, the whole forming three triangles, which, if not secured in their relative positions otherwise than by the mere transverse strength of the principals, would turn on the points *c*, *c*, Fig. 6615, the weight of the roof thrusting out the walls in the manner shown in the figure. There are two ways in which a truss of this kind may be prevented from spreading. 1st. The ends of the hammer-beams may be connected with the collar by tension pieces *a*, *a*, Fig. 6614, by which the thrust on the walls will be converted into a vertical pressure; 2nd. The hammer-beams may be kept in their places by struts *b*, *b*, the walls being made sufficiently strong by buttresses, or otherwise, to resist the thrust. In existing examples, we find sometimes one and sometimes the other of these plans followed, and occasionally both methods are combined in such a manner that it is often difficult to say what parts are in a state of compression, and what are in a state of tension. The roof of the great hall at Hampton Court, Fig. 6616, is very strong, and so securely tied, that were the bottom struts *b*, *b*, removed, there would be little danger of the principals thrusting out the walls; and, on the other hand, from the weight of the roof being carried down to a considerable distance

below the hammer-beams by the wall-posts, the walls themselves offer so much resistance to side thrust, that there would be no injurious strain on them were the tension pieces *a*, *a*, removed.

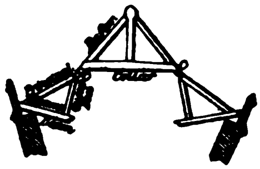
6614.



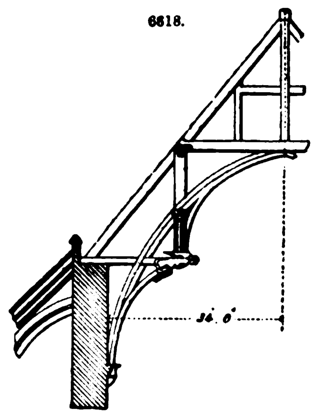
6617.



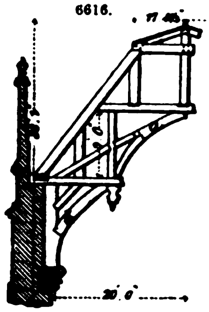
6615.



6618.



6616.



The construction of the roof of the hall at Eltham Palace, Kent, Fig. 6617, differs very considerably from that of the Hampton Court roof. The whole weight is thrown on the top of the wall, and the bottom pieces *b*, *b*, are merely ornamental, the tension pieces *a*, *a*, forming a complete tie. This has been shown by a partial failure which has taken place. The wall-plates having become rotten in consequence of the gutters being stripped of their lead, the weight has been thrown on the pseudo-struts, which have bent under the pressure, and forced out the upper portion of the walls.

The roof of Westminster Hall, Fig. 6618, is one of the finest examples now existing of open timbered roofs. The peculiar feature of this roof is an arched rib in three thicknesses, something on the principle of Philibert de Lorme. This is so slight, compared with the great span, that it is probable in designing the roof, the architect took full advantage of the support afforded by the thickness of the walls and the buttresses, if, indeed, the latter were not added at the time the present roof was erected, in 1395. It has been ascertained that the weight of the roof rests on the top of the walls, the lower part of the arched rib serving only to distribute the thrust, and to assist in preventing the hammer-beams from sliding on the walls.

The examples adduced are sufficient to show the general principles of building roofs of timber. For particulars of the manner in which the different members are framed together, and for the rules for determining their strength, see CONSTRUCTION.

TABLE I.—SCANTLINGS OF TIMBER FOR DIFFERENT SPANS, FROM 20 TO 30 FEET, FOR THE ROOF, FIG. 6604.

Span.	Tie-beam.	King-post.	Principal Rafters.	Struts.	Purlins.	Small Rafters.
feet.	inches.	inches.	inches.	inches.	inches.	inches.
20	9½ × 4	4 × 3	4 × 4	3½ × 2	8 × 4¾	3½ × 2
22	9½ × 5	5 × 3	5 × 3	3¾ × 2¼	8¼ × 5	3¾ × 2
24	10½ × 5	5 × 3½	5 × 3½	4 × 2½	8½ × 5	4 × 2
26	11½ × 5	5 × 4	5 × 4¼	4¼ × 2½	8¾ × 5	4¼ × 2
28	11½ × 6	6 × 4	6 × 3½	4½ × 2¾	8¾ × 5¼	4½ × 2
30	12½ × 6	6 × 4½	6 × 4	4¾ × 3	9 × 5½	4¾ × 2

In this Table the trusses are supposed to be not more than 10 ft. apart, the pitch of the roof about 27 degrees, the covering slate, and the timber Baltic pine, or other equally strong.

TABLE II.—SCANTLINGS FOR ROOFS, FROM 30 TO 46 FEET SPAN, FOR THE ROOF, FIG. 6605; TRUSSES 10 FEET APART.

Span.	Tie-beam.	Queen-posts.	Principal Rafters.	King-post.	Braces.	Purlins.	Small Rafters.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
32	10 × 4½	4½ × 4	5 × 4½	6¾ × 4½	3¾ × 2¼	8 × 4¾	3½ × 2
34	10 × 5	5 × 3½	5 × 5	6¾ × 5	4 × 2½	8¼ × 5	3¾ × 2
36	10½ × 5	5 × 4	5 × 5¾	7 × 5	4¼ × 2½	8½ × 5	4 × 2
38	10 × 6	6 × 3¾	6 × 6	7¼ × 6	4½ × 2½	8½ × 5	4 × 2
40	11 × 6	6 × 4	6 × 6	8 × 6	4½ × 2½	8¾ × 5	4¼ × 2
42	11½ × 6	6 × 4½	6¼ × 6	8¼ × 6	4½ × 2¾	8¾ × 5¼	4½ × 2
44	12 × 6	6 × 5	6½ × 6	8½ × 6	4½ × 3	9 × 5	4¾ × 2
46	12½ × 6	6 × 5½	7 × 6	9 × 6	4¾ × 3	9 × 5½	5 × 2

Pitch of the roof about 27 degrees, covering slate, and timber as already mentioned.

TABLE III.—SCANTLINGS FOR ROOFS OF FROM 46 TO 60 FEET SPAN, FOR ROOF IN FIG. 6606; TRUSSES 10 FEET APART.

Span.	Tie-beam.	Queen-posts.	Posts.	Principal Rafters.	Straining Beam.	Braces.	Purlins.	Small Rafters.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
48	11½ × 6	6 × 5¾	6 × 2¼	7½ × 6	8¼ × 6	4½ × 2¾	8½ × 5	4 × 2
50	12 × 6	6 × 6¼	6 × 2½	8½ × 6	8½ × 6	4½ × 2¾	8¾ × 5	4¼ × 2
52	12 × 6½	6 × 6¾	6 × 2¾	9¼ × 6	8¾ × 6	4¾ × 2¾	8¾ × 5¼	4¼ × 2
54	12 × 7	7 × 6¼	7 × 2¼	6½ × 7	9 × 6	5¾ × 2¾	8¾ × 5¼	4½ × 2
56	12 × 8	7 × 6¾	7 × 2½	7½ × 7	9¼ × 6	5 × 2¾	8¾ × 5¼	4½ × 2
58	12 × 8½	7 × 7¼	7 × 2¾	8¼ × 7	9½ × 7	5 × 2¾	9 × 5¼	4¾ × 2
60	12 × 9	7½ × 7	7 × 3	9 × 7	10 × 7	5 × 3	9 × 5½	4¾ × 2

TABLE IV.—SCANTLINGS FOR ROOFS, FROM 70 TO 80 FEET SPAN, FIG. 6609; TRUSSES 10 FEET APART.

Span.	Tie-beam.	Queen-posts.	Principal Rafters.	Straining Beam.
feet.	inches.	inches.	inches.	inches.
70	15 × 11½	9½ × 8	13 × 9½	12 × 9½
75	15 × 14	10 × 8½	13½ × 10	12 × 10
80	16 × 13	10½ × 9	14 × 10½	13 × 10½
85	16 × 14½	11 × 10	14½ × 11	13 × 11

TABLE V.—SCANTLINGS FOR ROOFS, FROM 20 TO 32 FEET SPAN, FIG. 6610; TRUSSES 10 FEET APART.

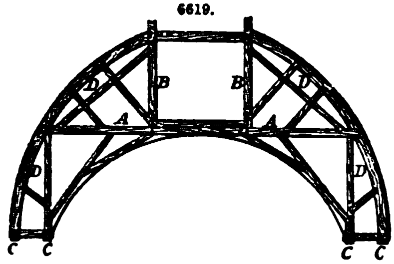
Span.	Tie-beam.	Curved Rib.	Suspending Pieces.		Purlins.	Common Rafters.
			No. of Pairs.	Scantlings of each Piece.		
feet.	inches.	inches.		inches.	inches.	inches.
20	8 × 4	4 × 4	3	4 × 2	8 × 5	3½ × 2
24	8 × 4	4¾ × 4	3	4 × 2	8 × 5	4 × 2
28	8 × 5	5¼ × 5	3	4 × 2¼	8½ × 5	4½ × 2
30	8½ × 5	6 × 5	3	4 × 2¼	8½ × 5	4¾ × 2
32	9 × 5½	6 × 5½	3	4 × 2½	8½ × 5	5 × 2

Domes or Cupolas.—A dome or cupola is a roof of which the base is a circle, an ellipse or a polygon, and its vertical section a curved line, concave towards the interior. Hence domes are called circular, elliptical, or polygonal, according to the figure of the base.

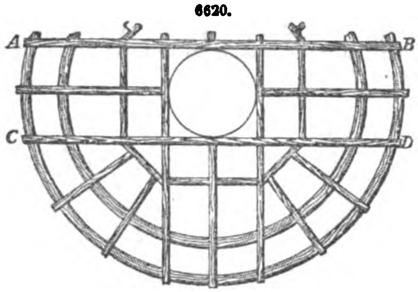
The most usual form for a dome is the spherical, in which case its plan is a circle, and section a segment of a circle. The top of a large dome is often furnished with a lantern, which is supported by the framing of the dome. The exterior and interior forms of a dome are not often alike, and in the space between, a staircase to the lantern is generally made. According to the space left between the external and internal domes, the framing must be designed. Sometimes the framing may be trussed with ties across the opening, but often the interior dome rises so high that ties cannot be introduced. Accordingly the construction of domes may be divided into that of domes which admit of horizontal ties, and domes without such ties. A truss for a dome where a horizontal tie can be introduced is shown in Fig. 6619. A A is the tie; B, B, posts, which may be continued to form the lantern; C, C, are continued curbs in two thicknesses, with the joints crossed and bolted

together; D D, a curved rib to support the rafters. This design is calculated for a span of about 60 ft., and may be extended to 120 ft.

6619.

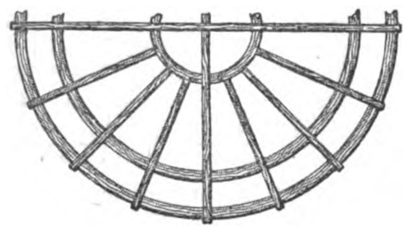


6620.



Two principal trusses may be placed across the opening parallel to each other, and at a distance apart equal to the diameter of the lantern, as A B, C D, Fig. 6620, with a sufficient number of half trusses to reduce the bearing of the rafters to a convenient length. By another arrangement, the two principal trusses may cross each other at right angles in the centre of the dome, the one being placed so much higher than the other as to prevent the ties interfering. This disposition is represented in Fig. 6621, and is the same as that adopted for the Dôme des Invalides at Paris, of which the external diameter is nearly 90 English feet.

6621.



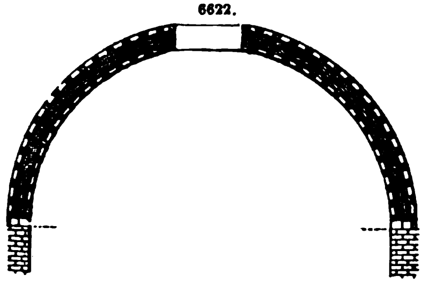
Domes without Horizontal Ties.—The construction of domes without horizontal cross-ties is not difficult when there is a sufficient tie round the base. The most simple method, and one which is particularly useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top, with a sufficient number of intermediate braces to prevent the ribs from yielding laterally.

When the pieces are long, and so much curved that they cannot be cut out of timber otherwise than across the grain, which reduces their strength, they should be put together in thicknesses, with the joints crossed, and well nailed together. In very large domes, they should be bolted or keyed together. The method of making curved ribs in thicknesses has been adopted in the construction of centres for arches from the earliest period of arch building, and it was first applied to the construction of domes by Philibert de Lorme, who gives the following scantlings for different sized domes;—

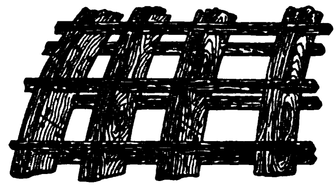
For domes of	24 ft.	diameter,	8 in.	by	1	in.
„	36	„	10	„	1½	„
„	60	„	13	„	2	„
„	90	„	13	„	2½	„
„	108	„	13	„	3	„

These ribs are formed of two thicknesses of the scantlings given above, and are placed about 2 ft. apart at the base. The rafters are notched upon them for receiving the boarding, and also horizontal ribs are notched on the inside, which gives a great degree of stiffness to the whole. Fig. 6622 is a section of a dome constructed in this manner, and Fig. 6623 a projection of a part of

6622.



6623.

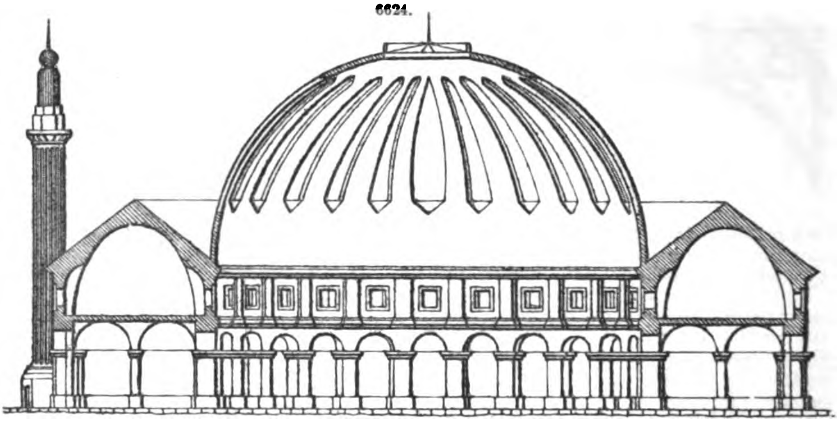


the dome, with the rafters and inside ribs. When a dome is of considerable magnitude, the curve of equilibrium should pass through the middle of the depth of the ribs, particularly if a heavy lantern rests upon them, otherwise the ribs should be within the curve of equilibrium, and they ought to be strutted to prevent their bending in. Or, if it be necessary for the external appearance of the dome that the curvature of the ribs should be without the curve of equilibrium, then an iron hoop may be put round at about one-third of the height to prevent the dome bursting outwards. This latter method was adopted in the external dome of the Church de la Salute at Venice. The outside dimensions are 80 ft. diameter, 40·5 high, and the lantern 39·5 ft. high; but the lantern is supported by a brick dome, which is considerably below the wooden one. The ribs of this dome

are 96 in number, and each rib is in four thicknesses; the four together make 5·5 in., so that each rib is 8·5 in. by 5·5 in. The iron hoop is 4·5 in. wide and ½ in. in thickness, and is placed at one-third of the height of the dome.

One of the finest applications of the system of De Lorme was the cupola over the Original Halle au Blé at Paris, completed in 1783, Fig. 6624. Although 129 ft. in diameter, its thickness did not

6624.

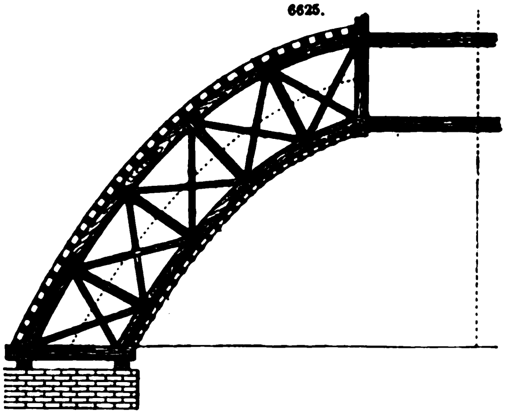


much exceed 1 ft., notwithstanding which it stood in perfect safety until destroyed by fire in 1802. The ribs of which it was composed were formed of planks in 9-ft. lengths, 13 in. wide, and 3 in. thick, bolted and tied together. At about one-third of the height of the dome from the springing every third rib was discontinued to admit of an opening, which was glazed. The ribs were about 2½ ft. apart at the base, and those next the openings were formed with four thicknesses of planks, all the others having only three. At the top of the dome the ribs were framed into a circular ring of timber, leaving an open space which was protected by a glazed canopy, with perforations for the ventilation of the building.

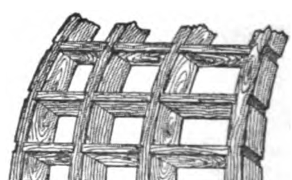
No modern example, executed in wood, has surpassed this dome, either for simplicity or strength, and the facilities afforded at the present day by the use of wrought iron, has probably rendered the execution of domes of this magnitude in wood a thing of the past, except for temporary purposes.

When a dome is intended to support a heavy lantern, it may require the principal ribs to be stronger than can be obtained out of a single piece of timber, but the framing may always be made sufficiently strong by using two ribs, with braces between, and tied together by radial pieces across from rib to rib. A truss of this form, in Fig. 6625, would sustain a very heavy lantern if the curve of equilibrium were to pass in the middle between the ribs, as the dotted line does in the figure.

6625.



6626.

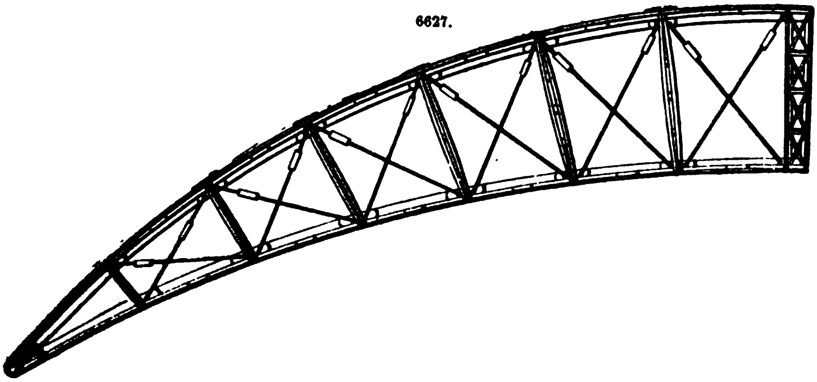


Trusses somewhat similar to that in Fig. 6625 were used for the roof and semi-domes of the Dublin Exhibition building in 1853. Each truss was formed of two concentric vertically-laminated ribs about 5 ft. apart, with intermediate diagonal framing, in which both struts and ties were formed of timber. The upper or outer rib consisted of ten lamina 1¼ to 2 in. in thickness, and 4 to 18 in. in depth. The breadth of the rib at top was 18 in., and at bottom only 3 in., each being stepped back from the lower edge of the preceding. The inner rib was formed of six 1¼ and 2 in. lamina, and was 12 in. deep and 10 in. wide. The span of the semi-domes of the great hall was 100 ft., and the principal trusses were 25 ft. apart.

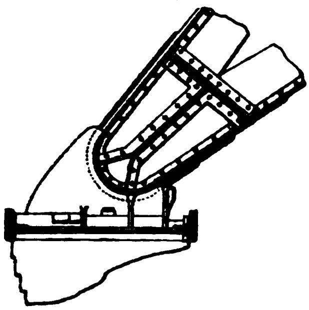
Where a light dome is required, without occupying much space, the ribs may be placed so near to each other that the boards can be fixed to them without rafters, or short struts may be placed between the ribs, as shown in Fig. 6626.

Iron Domes.—The most remarkable examples of iron domes are to be found in those covering the Royal Albert Hall at Kensington, and the Exhibition building at Vienna. The plan of the former dome is not circular, but oval with four centres. Some idea of its size may be gathered from the following facts. Its height from the arena to the spring of the roof is about 135 ft., and to the top of the lantern, which surmounts the roof, is about 150 ft. The span of the roof is 219 ft. 4 in. by 185 ft. 4 in.; and the span of the outer walls is 272 ft. by 238 ft. The engravings of the roof, Figs. 6627 to 6640, show clearly the design and construction of the ironwork. Fig. 6641 is a

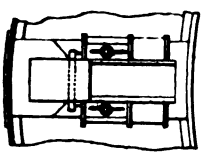
6627.



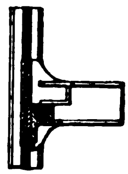
6628.



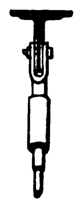
6630.



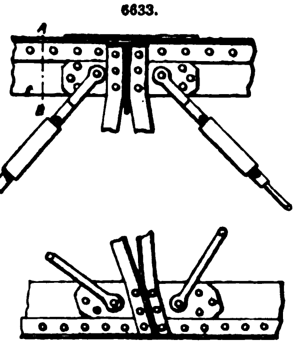
6631.



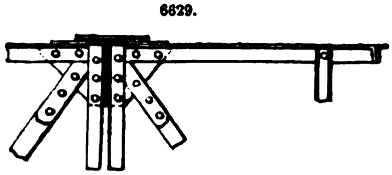
6632.



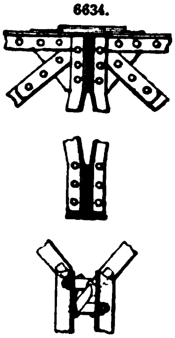
6633.



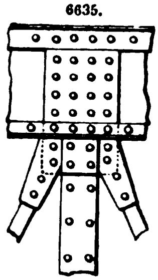
6629.



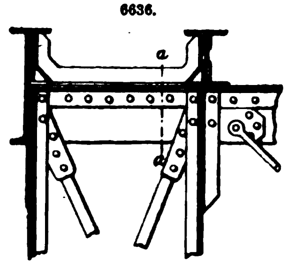
6634.



6635.



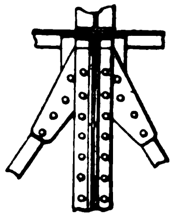
6636.



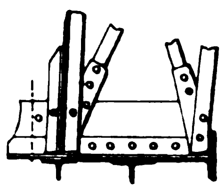
longitudinal section through the longer axis of the roof, where the clear span is 219 ft. 4 in. Fig. 6627 is a section through the shorter axis, and Fig. 6640 is a plan of one quarter of the roof. All

these figures show the general disposition of the principal and the purlins. Around the wall, at the level of the springing of the roof, is a wrought-iron wall-plate, shown in the drawing, formed of a

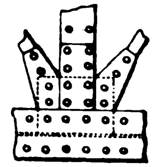
6637.



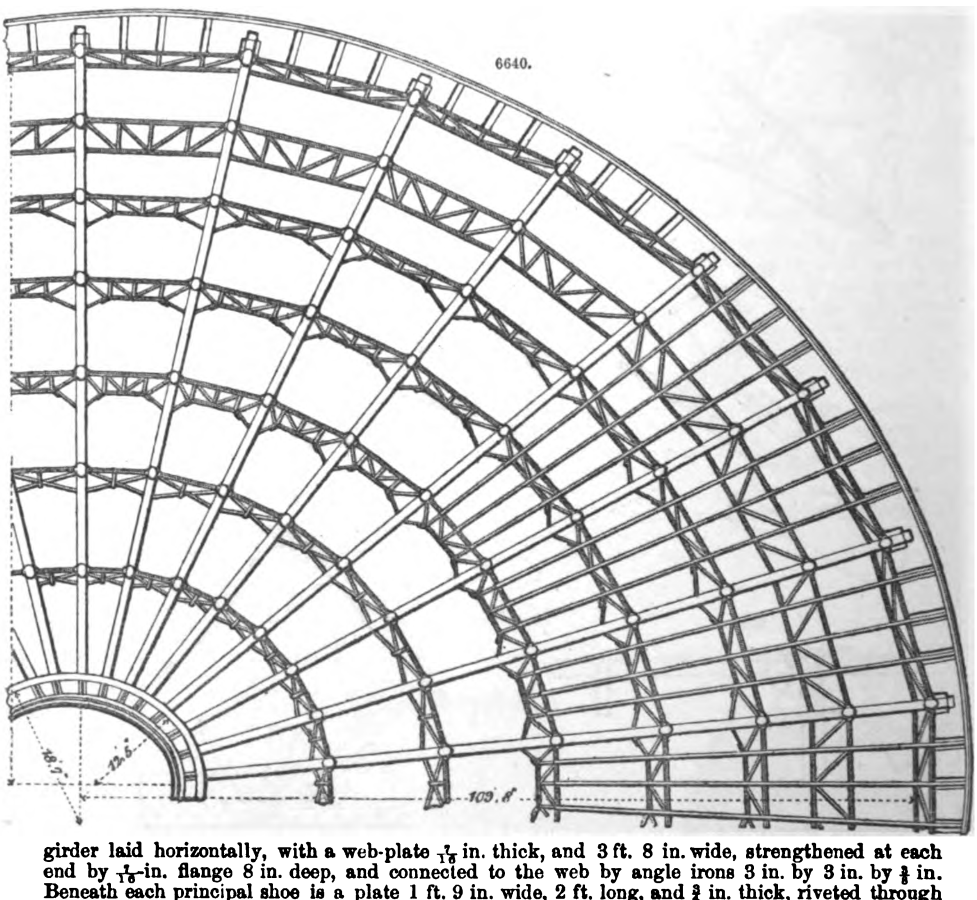
6638.



6639.



6640.

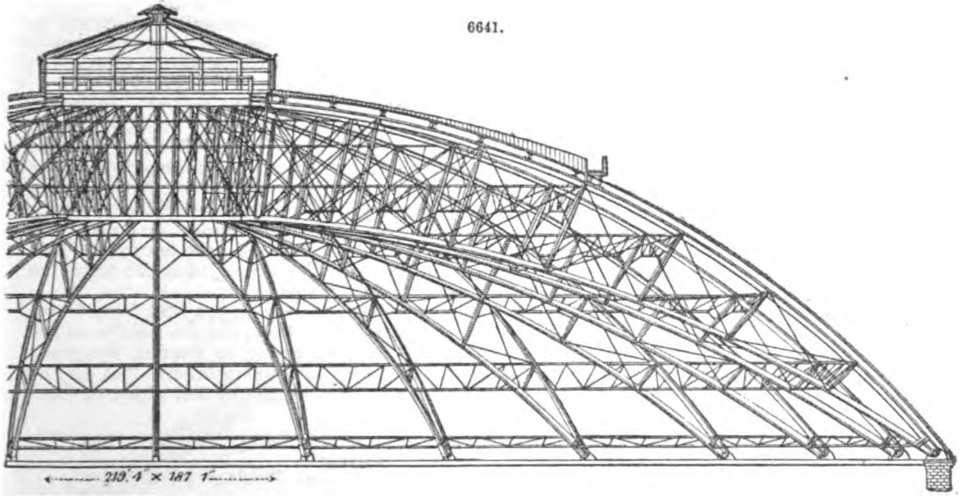


girder laid horizontally, with a web-plate $\frac{7}{16}$ in. thick, and 3 ft. 8 in. wide, strengthened at each end by $\frac{7}{16}$-in. flange 8 in. deep, and connected to the web by angle irons 3 in. by 3 in. by $\frac{3}{8}$ in. Beneath each principal shoe is a plate 1 ft. 9 in. wide, 2 ft. long, and $\frac{3}{4}$ in. thick, riveted through the web-plate to an upper plate $1\frac{3}{4}$ in. thick. Upon this plate is secured by keys the cast-iron shoe in which the heel of the principal rests. It is 2 ft. $9\frac{3}{4}$ in. deep and 1 ft. $1\frac{3}{4}$ in. broad, and is formed with a central member, 1 ft. $\frac{3}{4}$ in. wide, projecting from each side of the shoe so as to clip the upper plate riveted to the wall-girder, and to which it is secured by wrought-iron keys at the back of the shoe. A 1-in. bolt also passes through a slot in the projection on each side of the shoe, Fig. 6628, and secures it to the wall-plate. The face of the shoe receiving the principal is curved to a radius of 10 in., corresponding to that of the heel of the principal. The upper member of the principal is struck with a radius of 145 ft., the lower member has a radius of 114 ft. on the smallest diameter of the roof, increasing to the maximum span. The details of the principals are shown fully in Figs. 6627 to 6641. The upper members of the ribs are 9 in. deep and 11 in. wide, formed of a top flange $\frac{5}{16}$ in. thick, secured to a web of the same thickness by angle irons 3 in. by 3 in. by $\frac{5}{16}$ in.; the bottom member of the rib has the same dimensions, but the flange-plate is omitted. The upper and lower chords of the principals are connected and stiffened with wrought-iron struts, as shown in Figs. 6627 and 6641.

The struts are formed of four angle irons $2\frac{1}{2}$ in. by $2\frac{1}{2}$ in. by $\frac{5}{16}$ in., disposed in pairs on each side of the web-plates of the top and bottom members of the principal, and kept separated by

distance pieces of cast iron, of the form seen in the engraving. The bays between the struts are occupied with diagonal bracing, the tie-rods being 1¼ in. diameter, forked at the ends to receive the web-plates, and swelled at the upper side to 1⅜ in. diameter.

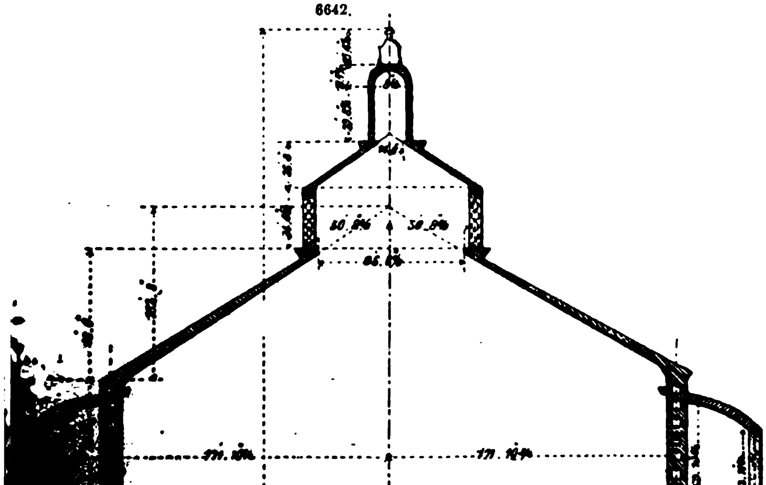
6641.



Each truss-rod is formed of two pieces, these pieces being coupled together by an adjusting nut, 1 ft. in length, to regulate the length of the rod. At the heel of the principal, the top and bottom member of the ribs meet, and are formed into one piece by means of a cover plate stiffened with angle irons in the manner shown in Fig. 6628.

Towards the centre the principals converge to a central curb, which is elliptical, and corresponds with the curves of the outer wall-plate. This curb, Figs. 6640 and 6641, is 17 ft. 6¼ in. in depth, which corresponds to the maximum depth of the rib. It is a double ring, the top 2 ft. 6 in. deep, and the upper part is formed of two girders; the outer one, 9 in. deep, is made up of a web-plate and angle iron; the inner one is 1 ft. 7 in. deep, the top member being on the same level as the outer ring, while the web extends 10 in. lower, and forms a curb, against which the upper chord of the main rib abuts and is bolted. A plate ½ in. thick and 2 ft. 9 in. wide, connects these inner and outer girders, and, overlying the top of the principals, ties them together with each other and with the curb. The construction of the bottom member of the curb differs from the top. It consists of a ½-in. web-plate, which is riveted to the under side of the lower chord of the principals, and stiffened with a flange on the inner side 8 in. deep and ½ in. thick, the web being also strengthened with two T irons 6 in. by 8 in. by ⅝ in. The space of 17 ft. 6¼ in. between the top and bottom portions of the curb is filled with vertical struts of plate and angle irons, and diagonal struts 3 in. wide by ⅝ in. thick. On the outside and inside curved faces of the curb diagonal bracing runs round the complete

6642.



ellipses, as in Fig. 6641, and in the details. The principals are connected by seven rows of purlins, arranged in lines parallel to the plan of the building. These decrease in strength from the

springing to the crown of the roof, and the heaviest ones are shown in the figures. They are 5 ft. 11 in. deep, the top and bottom members being formed of angle iron 3 in. by 3 in. by $\frac{7}{16}$ in., and are connected by intermediate standards of channel iron, the bays being braced with flat bars 3 in. by $\frac{3}{8}$ in. The first purlin, placed a little above the springing of the roof, differs from the others in being only 2 ft. 3 in. deep. At their intersection with the principals connections are made by means of gusset-plates on the top of the purlins; at intervals varying from the springing towards the crown, run a converging series of light channel iron. A portion of the enclosure is roofed over, but a central elliptical space 100 ft. by 138 ft. is left to form a skylight.

The other example of iron domes is that which formed the roof of the central space in the Vienna Exhibition of 1873. The main dimensions, which far exceed all ordinary limits, are shown in the diagram. The roof of the rotunda, Fig. 6642, is made of iron plates. The lower edge is strengthened and supported by a heavy wrought-iron curb, or continuous circular box-girder. The aperture on the top is stiffened by another curb, and on this curb is erected a lantern, from which the whole space below is lighted. If the roof had been made of plate iron unstiffened, then it would, for so great a span, have probably sagged between the upper and the lower curbs. To prevent this the whole structure is stiffened by heavy girders of plate iron running from curb to curb, while to prevent distortion in any other way ring-girders at right angles to the rafter-girders run round the roof. All these girders have been put outside the roof instead of inside.

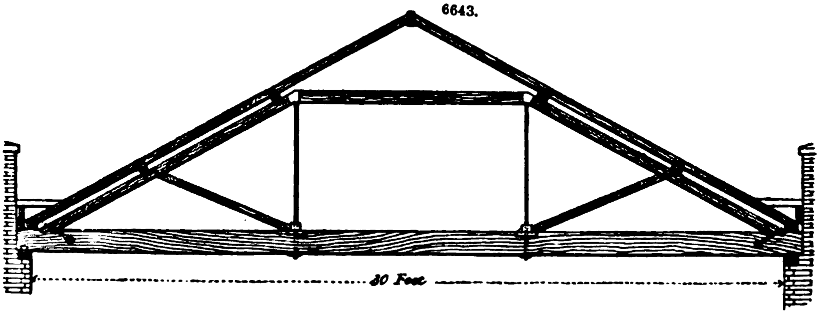
Coverings for Timber Roofs.—The coverings used for timber roofs are copper, lead, iron, tinned iron, slates of different kinds, tiles, shingles, and thatch of reeds or straw, and the relative degree of slope which each should have is determined by the mode of laying or forming the joints. Taking the angle for slates to be $26\frac{1}{2}$°, the following Table will show the inclination that may be given for other materials, and the weight of each material on a superficial foot of the inclined surface;—

Kind of Covering.	Inclination to the Horizon.	Height of Roof in parts of Space.	Weight per Super. Foot.
	° ′		lbs. lbs.
Asphalted felt	3 50	$\frac{1}{30}$	·3 to ·4
Tin	..	..	·7 „ 1·25
Copper	..	..	·8 „ 1·25
Lead	7 36	$\frac{1}{15}$	5·0 „ 7·0
Zinc	..	..	1·25 „ 2·0
Slates, large	22 0	$\frac{1}{5}$	9·0 „ 11·0
„ ordinary	26 33	$\frac{1}{4}$	5·0 „ 9·0
Thin slabs of stone or flags ..	29 41	$\frac{2}{7}$	20·0 „ 25·0
Plain tiles	..	..	15·0 „ 18·0
Pantiles	24 0	$\frac{2}{9}$	6·0 „ 8·0
Thatch of straw, &c...	45 0	$\frac{1}{2}$	6·0 „ 10·0

Whenever it is desired to make a roof for a dwelling-house which shall be cool in summer and warm in winter, and be durable as well, it should always be boarded over before the slates are put on. In the roofs of ordinary dwelling-houses this is not done, and hence it arises that the garrets, if the house happens to be provided with them, are frequently unendurable in summer and winter from the excessive warmth at one time and extreme cold at the other.

Compound Roofs.—Roofs are occasionally constructed of timber and iron, and when the two materials are judiciously and scientifically combined, the compound structure is of an economical character. In modern roofs the use of wrought iron in combination with wood has been more extensive than formerly. Instead of being confined to straps and screw-bolts, iron is now used for king and queen bolts, ties and struts, and sometimes for principal rafters and purlins. But for common rafters, which require to be battened or boarded over, and for tie-beams, which have to carry a ceiling, wood has the advantage, from the facility with which other timbers can be fixed to it. When the roof is not required to support a ceiling, an iron tie-rod is preferable to a wooden beam. For purlins, principal rafters, and struts, rolled iron can now be provided of almost any suitable shape and size.

6643.



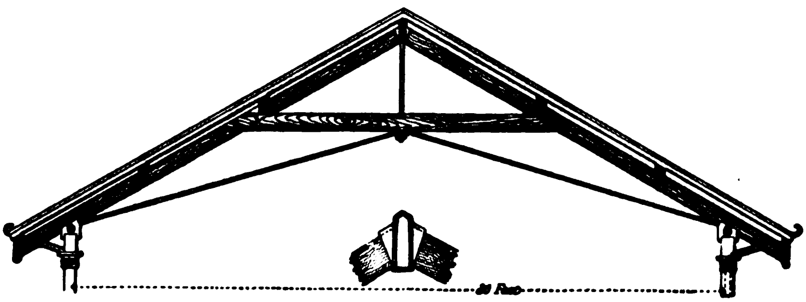
The simplest application of wrought iron in such cases is in Fig. 6643, the same as the ordinary queen-post truss, except that iron rods are substituted for the queen-posts. The heads of these

rods are fixed to the iron sockets, which take the ends of the straining beam and principal rafters. The lower ends pass through the cast-iron shoes, which receive the feet of the struts that support the principal rafters, and are continued through the tie-beam and secured by a nut, which enables the bolts to be screwed up tight.

Fig. 6644 shows a form of roof suitable for a shed, where as much clear space as possible in height is required. The strain on the rafters, where connected by the collar-beam, is relieved by iron tie-rods, which are suspended at a considerable height by the king-bolt, to which they are secured by a screwed end and nut. The lower ends of the ties are fixed to the cast-iron boxes, as shown in Fig. 6645, by which the rafters are attached to the longitudinal bearers over the columns which support the structure.

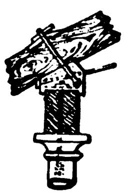
A better arrangement, if it did not interfere with the space in the roof, would be to keep the tie-rods horizontal, or nearly so, and to continue the king-bolt down to it, as there will always be a tendency to thrust out the sides when the ties are so much inclined, as in Fig. 6646, the arrangement by which the rafters and ridge pieces are secured in a cast-iron socket.

6644.

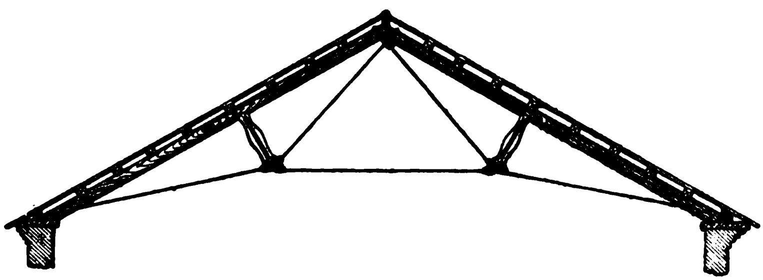


6645.

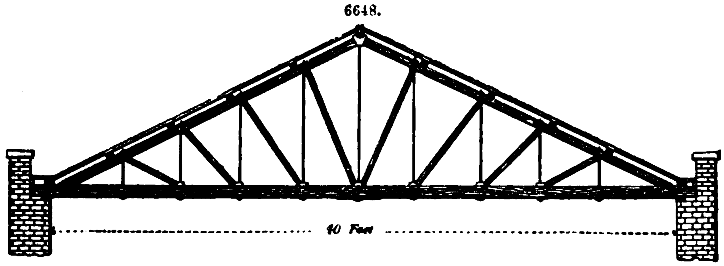
6646.



6647.



6648.



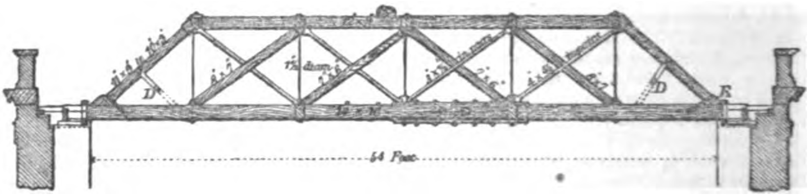
A better arrangement for an open roof, with iron ties and struts, is shown in Fig. 6647. The tie-rods are made to pass through the feet of the rafters, and are secured to a continuous plate of wood, which rests on the walls. The struts in the drawing are supposed to be cast iron, but a piece of wrought T or angle iron would be preferable, and could be as readily secured to the ties and rafters. Fig. 6648 is a very superior arrangement for a roof which has to carry a ceiling. In consequence of the suspension of the tie-beam at so many points, the timber is not required to be of so large a scantling as in the ordinary queen-post truss. In long spans, owing to the length required for some of the struts, wrought iron should be used in preference to wood. There is no reason why the principle on which girders are used in the construction of bridges should not be applied to roofs.

A good example of a compound roof is represented in Figs. 6649 to 6652. It is erected over the lecture room at the London University, and possesses the somewhat peculiar feature of compound purlins of wood and iron combined.

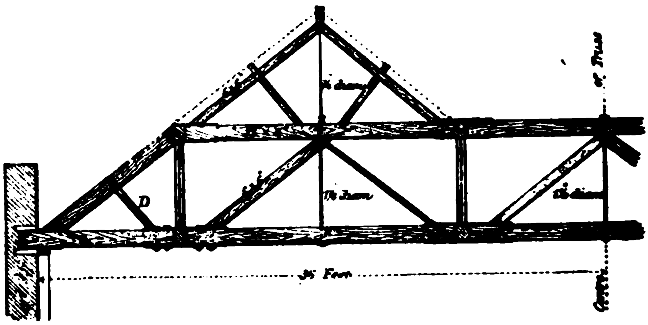
Cast iron has also been extensively used in combination with wrought iron and wood in the

construction of roofs, but its adoption is not to be recommended where there is a liability to sudden strains, particularly cross strains.

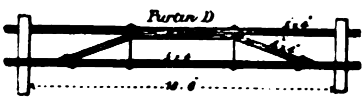
6649.



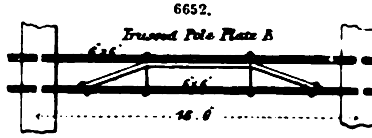
6650.



6651.



6652.



Iron Roofs.—The use of cast and wrought iron for roofs has so many advantages that their employment, especially that of the latter, is very general. Economy, lightness, portability, and facility of erection render this material peculiarly well adapted for use in all countries, and particularly so in those in which ordinary building materials are scarce, and skilled labour of an expensive character.

Arched Iron Roofs.—Roof principals of the first class having a horizontal thrust must in their construction have such stability at the springing point as will offer to this thrust the necessary resistance.

The abutments for arched principals can be obtained in various ways. The most natural method might at first sight appear to be in making the walls on which the arch rests sufficiently strong. In almost all cases, however, this is too expensive, and when it is adopted, the wall is only thickened at the points where the principals rest, the part thus thickened forming a buttress or abutment. In most instances a tie is introduced to take the horizontal thrust, as may be seen in some of the examples.

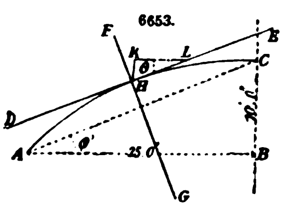
The equation for the horizontal strain at any point of an arch is $H = \frac{\int w\,d\,x}{y}$, in which H = the horizontal strain, w = the load between the centre of the arch and the given point. If the crown be taken as the origin, x and y are the two co-ordinates. From this equation may be deduced the one commonly used in determining the strain at the centre of any arch, girder, or suspension chain. Integrating we obtain $H = \frac{w\,x^2}{2\,y}$. When $x = o$ $H = o$. When $x = \frac{L}{2}$, as it is for the central strain, the equation becomes $H = \frac{w\,L^2}{8}$, but $w\,L = W$, and $y = D$, so that we obtain $H = \frac{W\,L}{8\,D}$, the same equation deduced in our article Materials of Construction, Strength of. The other strain to be determined is the resultant pressure at any point, and is compounded of two others, the horizontal strain and the weight. The resultant pressure acts at a tangent to the line of equilibrium, and may be thus obtained;—Put S for the resultant strain, and θ for the angle the line of pressure makes with the vertical, and we have $S = H$ cosecant θ.

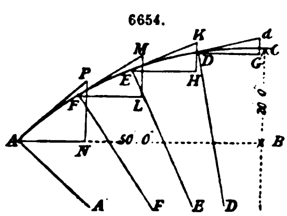
It has already been stated that arched roofs may be classed under one of two heads, those having solid and those having open or braced webs. The first of these will now be considered, for which purpose it is necessary to have clear ideas of the general manner in which the arch is affected by strains. On the supposition of a uniformly distributed load, and that the form of the arch is a parabola, the horizontal thrust may be assumed to be constant from the crown to the springings. This thrust answers to the strain at the crown, and has been ascertained by the above formula.

This, it will be seen, is the same formula that obtains for the strain on the flanges at the centre of a girder having the same span as the arch, and a depth equal to its rise. In the diagram, Fig. 6653, let $L = 50$, $R = 10$ ft. 0 in., and making $W = 20$ tons, the value of the central strain is $S = \frac{20 \times 50}{8 \times 10} = 12 \cdot 5$ tons. Similarly, the strain at any other point may be found by calculation, but it is not so correct as that given by a diagram, for the reason, already stated, that the conditions assumed in theory and in the calculation do not actually prevail when the arch takes its real form. We will first ascertain the strain by calculation at any given point, H in Fig. 6653. Let W^1 equal the load upon the arch situated between the crown and the point H, and S the strain already found at the crown. Putting S^1 for the strain at H, the equation becomes $S^1 = \sqrt{S^2 + W_1{}^2}$. In the present instance $S = 12 \cdot 5$ and $W_1 = 5$ tons; so that $S^1 = \sqrt{12 \cdot 5^2 + 5^2} = 13 \cdot 46$ tons, equals the strain at the point H. This is a special example, but generally, if S be the strain at the crown, W the weight between the crown and any point x where the strain is required, then the strain S^1 at that point is obtained from the formula $S^1 = \sqrt{S^2 + W^2}$.

It is obvious that the greater the discrepancy between the real form of an arch and a parabola, the wider will be the departure in practice from the results arrived at by pure theory. We may now proceed to calculate our strains by diagram, and first for the strain at the crown.

Referring to Fig. 6653, let F G represent a portion of the radius of the arch; draw D E at right angles to it. D E will consequently be a tangent to the arch at the point H. Make H K, drawn vertically, equal to the load situated between the crown of the arch and the point H. Draw K L horizontally to meet H E at L, then K L is equal to the strain at the crown C. In Fig. 6653, H K is made equal to 5 tons, on a scale of 20 tons to 1 in., and K L measures exactly 12·5 tons by the same scale, which is the value already found for the central strain by calculation. As the strain at the crown is horizontal, the calculation and the diagram coincide accurately in the result, which is not the case at any other point of the arch, the discrepancy increasing the nearer the point approaches the springing. It is not difficult to demonstrate this mathematically. In the triangle H K L we have H K = K L × tangent of angle K L H. Put angle K L H = θ, then H K = K L × tan. θ. Draw the line A C, then A C is parallel to D E, and the triangles H K L and A B C are similar. Consequently the angle K L H equals angle B A C. Calling this angle θ' we have $\theta = \theta'$ and H K = K L × tan. θ_1. By construction the tangent of angle $\theta' = \frac{BC}{AB}$. And $BC = R$ and $AB =$ half span of arch $= \frac{L}{2}$, so tan. $\theta' = \frac{R}{\frac{L}{2}}$. Substituting this value in the equation, we obtain $HK = KL \times \frac{R}{\frac{L}{2}}$. Referring to the diagram in Fig. 6653, and using the same notation as before, $HK = \frac{W}{4}$ and $KL = S =$ the strain at the centre of arch. Putting in these values in the formula we get $S = \frac{\frac{W}{4}}{\frac{2R}{L}} = \frac{W \times L}{8R}$, which is the formula given at the commencement of our article. It should be remarked here that the value of R in both Figs. 6653 and 6654 is about twice that which would be given to it in practically designing a roof. The reason it is so proportioned in the diagrams is to allow the construction of the strains to be better shown, which would not have been the case had the arch been drawn too flat. The space at our command does not permit of the diagrams being made on the same scale as they would be in the engineer's and architect's office.



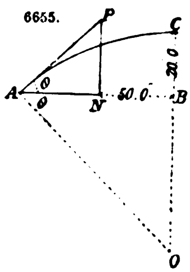


Having shown the method of ascertaining by diagram and calculation the amount of the central strain, it now remains to find that at any other point by the former mode of analysis. Let us suppose that it is required to determine the strains at five equidistant points of the arch represented in Fig. 6654. That at C has been already determined for the case in Fig. 6653, and can be equally readily obtained for that in Fig. 6654. In this instance $L = 100$, $W = 40$, and $R = 20$, and the central strain S will be equal to 25 tons. To determine the strains at the other points D, E, F, and A, draw the lines D D′, E E′, F F′, A A′, towards the centre of the circle of which the arch is a segment. They are therefore parts of the several radii, and the lines D J, E K, F M, and A P, drawn perpendicularly to them respectively, will be tangents to the arch at the points where the several strains are required. From these points draw the horizontal lines D G, E H, F L, and A N, making

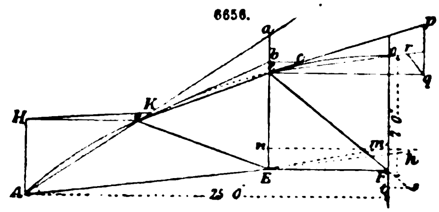
each equal the strain at the centre, or equal to 25 tons. From the end of these lines draw verticals to meet the tangents, and the several strains at the points D, E, F, G, will be given by the lines D J, E K, F M, A P. If they be measured on the diagram upon a scale of 20 tons to 1 inch, they will read 25·5, 27, 29·5, and 34·5 tons respectively, or rather more than what they would amount to by calculation by the ordinary formula. There is, however, an accurate method of calculating the strains at any point which will serve to check those obtained by the aid of a diagram. The strains vary as the secant of the angle which a tangent at any point makes with a horizontal line. When this angle is known the strains can be determined.

In Fig. 6655, let the diagram be a reproduction of that in Fig. 6654, only on a smaller scale, in order to allow of the centre of the circle being shown. Suppose it is required to find the strain at the springing of the arch; as before, let A P = S^1 = required strain, S = that already found for the crown, and put θ for the angle P A N. Since the angle P A O is a right angle, the angle P A N is the complement of the angle B A O. Making this latter equal to θ', we have $\theta = (90° - \theta')$. If the angle θ' were known, the problem is solved. To find θ', we use the trigonometrical equation of the triangle A B O, in which the angle A B O is a right angle, and B O = A B × tan. θ', or tan. $\theta' = \frac{\text{B O}}{\text{A B}}$. But B O is equal to the radius of the arch minus its rise. Calling the radius of the circle R^1, then B O = R^1 − R. When the span and rise of an arch are given, the radius is found from the equation $R^1 = \frac{L^2 + R^2}{2\,R}$, when L is the half span. In this case $R^1 = \frac{50^2 + 20^2}{2 + 20} = 72·5$ ft. From this B O = 52·5 ft. By logarithms we have, log. tan. θ' = log. 52·5 − log. 50 + 10. Solving we find $\theta' = 46° 24'$. Consequently $\theta' = 43° 36'$. Referring to Fig. 6655 in the triangle A P N, $\text{A P} = \frac{\text{A N}}{\cos.\ \theta}$. But A P = S′ and A N = S′, therefore $S' = \frac{S}{\cos.\ \theta}$. By logarithms log. S′ = log. S − log. cos. θ + 10. Putting in the values for S and θ', we have log. S^1 = log. 25 − log. cos. 43° 36′ + 10. Solving for S^1 we finally obtain S^1 = 34·52 tons, which is the same value as that given by the diagram in Fig. 6654. If the values of the secants of the other angles made by the tangents with the horizontal lines be found, the resulting strains at those points can be also determined. As many points may be taken as considered desirable, but unless the arch is very large, four points will be sufficient for practical purposes.

6655.



6656.



Roofs of trussed ironwork in the arch form are especially well adapted for roofs of large span, not only on account of the reasons already mentioned, but because the strains upon the bracing are comparatively small, and therefore the full value of the trussed arch is not obtained in examples of limited span. The example of a trussed arch roof, Fig. 6656, has a span of 50 ft., a depth of truss of 7 ft., and is supposed to be loaded with 2 tons on the whole roof, or 1 ton on the half principal shown in the figure. The thick lines represent the parts in compression, and the thin ones those in tension, from which it is at once evident that the whole of the upper flange or bow is in compression, and the lower or tie in tension. Also B E, C F are struts, and C E, D F ties. When the design of a trussed roof is of a very complicated nature, it is not easy to determine, as in the present case, by mere inspection those parts which are in compression and those which are in tension. It is not until some progress has been made in the analysis of the strains that the manner in which they affect the various members of the truss becomes apparent. Having ascertained those bars which are struts and those which are ties, the next point is to examine into the distribution of the load. Referring to Fig. 6656, we have a total load of 1 ton upon the half principal, and it is divided as follows;—There will be one-third situated at each of the points B and C, and one-sixth at A and D. Thus we shall have at B and C a weight of 0·33 ton, and at A and D a weight of 0·165 ton. It will, however, be apparent, by a glance at the diagram, that the weight of 0·165 ton at A is supported directly by the vertical reaction of the abutment, and consequently produces no strain whatever on any part of the truss. Its action may be therefore ignored, and the total weight on the principal producing strain on its various parts will be equal to 0·825 ton instead of 1 ton. This theoretical assumption will not hold, unless the distance A B or unsupported length of the rafter, between the abutment and the strut B E, be of sufficiently limited dimensions so as not to allow of any bending taking place. This is always practically effected by subdividing the roof, by the introduction of the sloping struts, into lengths which are too small to permit any appreciable deflection.

The relative positions of the subdivisions of the load being adjusted, the next operation is to ascertain the strains upon the various bars, and in the analysis, as in all other calculations, we must always proceed from the known to the unknown. At the point of support A, the vertical reaction producing strain upon the roof is the sum of the weight at B, C, and D, since they must all be ultimately transferred to that point. This reaction is therefore equal to 0·825 ton. We have

therefore three forces at the point A, making equilibrium at the point A, namely, the vertical reaction of 0·825 ton, the strain along A B, and the strain in A E. It must be kept in mind that although in practice the arch is a segment of a circle, it is supposed in the diagram to consist of the polygonally-shaped figure A B C D, the length A B, B C, and C D being straight lines. Each of these is, in fact, regarded as a separate bar, or part of the upper flange. On a scale of 1 ton to the inch, make A H equal to 0·825 ton; join A B, and produce the line to any convenient length. From the point H, draw H K parallel to A E, meeting A B produced in K. Measuring by the same scale, A K will give the strain upon A B, and H K that upon A E, respectively equal to 1·90 and 1·57 ton. It should be observed here, that were A B in the same straight line with B C, as occurs in the ordinary inclined rafter, then the strain upon A B would be the same as that upon B C, plus the additional strain due to the weight at B. But as in the diagram the direction of the different bars of the arch is continually changing, the question is considerably more complicated. To find the strain upon B C, we must find the resultant of the strain upon A B and the weight at B. Upon A B produced, lay off B a = A K equal to 1·90, the strain already found for A B; draw ab vertically equal to the weight at B equal to 0·33 ton; join B b, which is the resultant required. From the point B, draw bd parallel to B E, and B d will give the strain upon B C, and bd that upon the strut B E. There now remains only the central bar C D of the upper flange upon which to ascertain the strain. This, allowing for the change of direction, will evidently be less than that upon B C, by the action of the weight at C, plus the pull on the queen-rod C E. Before the strain upon C D can be determined, that upon C E must first be obtained. This obviously proceeds from the pull at the point E, for since C E is a tie it cannot be affected by the weight at the apex C, which is supported directly by the arch and the strut C F. At the point E, there are two forces acting, a compression along B E, and a tension along A E, and the resultant of these will pull upon both C E and E F. The amount of these pulls or tensile strains may be thus ascertained. Produce A E to any convenient length, make E h equal to H K, equal to the strain upon A E; from h draw hm parallel to B E. The resultant of the strains in A E and B E will be represented by E m. From m draw mn parallel to E F, and mn will be the strain upon E F, and E n the pull upon the queen-rod C E. The compression upon C D can now be calculated. Produce B C, and upon it lay off C p = B d; from p draw pq, equal to the weight 0·33, at C plus the pull E m; from q draw qr parallel to C F, and the strain upon C D is measured by C r, and that upon C F by qr. The question of what becomes of the weight D at the central apex will probably be now demanded. As D F is a tie, the whole of the weight D is conveyed in equal subdivisions to each of the two abutments, and it has already been accounted for, since it was included in the value of A H, which was made equal to the vertical reaction at A. There is yet one more strain to be determined, and that is the pull on the king-rod D F. The rod D F can only be affected by the strain upon the strut C F, since it is at right angles to the tie E F. But the corresponding strut upon the other half of the girder will bring a similar strain upon D F; so that by producing C F, making F S equal to twice qr, and drawing S t parallel to E F, the total strain upon D F will equal F t. The strain upon D F is in fact the vertical resultant of the strains in C F, and the corresponding strut upon the other half of the roof.

The strains having been determined, they should be tabulated as in Table I., and preserved for future reference. Before, however, considering the analysis as thoroughly trustworthy, a few of the strains should be checked by some independent method, as errors will frequently occur in estimating them by means of a diagram, which are only perceived by employing another process of analyis. The strain upon E F may be checked by drawing from H the line H B parallel to E F. The line H B will equal nm, the strain already found.

TABLE I.

Bars.	Strains.	
A B	+ 1·90	Arch.
B C	+ 1·90	
C D	+ 1·65	
A E	− 1·58	Tie-rod.
E F	− 1·33	
B E	+ 0·25	Struts.
C F	+ 0·22	
C E	− 0·25	Ties.
D F	− 0·22	

There is this general principle to be borne in mind in determining all strains upon trussed constructions by diagram. Whatever may be the amount arrived at by summation, if the same value for the strain is also obtained by an independent operation, it is scarcely within the limits of possibility that it should be otherwise than correct. As an example of our meaning, take the strain found on the end of the bow A B. It is determined at once by the plotting upon the vertical line A H the reaction of the total load upon the half roof. But if each weight were treated seriatim, the sum of the separate strains would be found to equal that obtained in the diagram. It will be of great advantage to those who are unacquainted with the method of analyzing strains by graphical diagrams to work this out for themselves on a large scale, and tabulate the several strains arising from each weight. The strain on the central bar of the arch C D may be checked by calculation. Let S equal the strain, L the half span, G the distance of the centre of gravity of the half load from the centre of the girder, D the depth of the truss, and W the total load upon the whole roof. Then we have $S = \frac{W\,(L - G)}{2 \times D}$. Substituting in this equation the values for the letters, we get

$S = \frac{2\,(25 - 12\cdot95)}{2 \times 7}$, and solving the equation, $S = 1\cdot72$ ton, which differs only by $0\cdot07$ from that arrived at in the diagram, a quantity that may be regarded as inappreciable. In conclusion, it should be mentioned that wherever a trussed principal is employed, in which a sloping rafter is used instead of an arch, the method given in the present case is not applicable. It is not difficult, however, to apply another method which gives equally true results.

In the construction of wrought-iron arched roof principals, the rules by which stone arches are designed need not be adhered to. A stone arch must be of sufficient thickness to enclose within itself all possible lines of pressure resulting from various loads, because it is assumed that the voussoirs of an arch cannot well resist a transverse strain. In an iron arch, however, a material so specially suited to resist transverse strains is employed, that the outline of the arch may be designed without strict regard to the lines of pressure, if these are duly considered in determining the dimensions of the material.

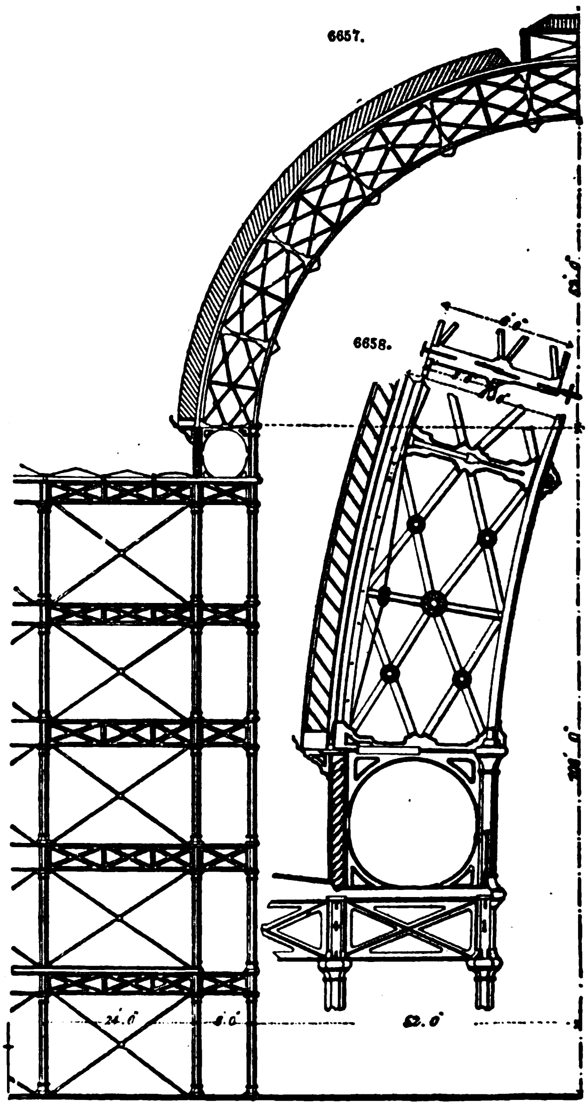
The sections of arched ribs may, like those of girders, be made in many different ways. For small spans a single web-plate is generally used, but where the rib is more than 12 in. deep, a lattice or trellis system is preferable, as affording the necessary strength with a more elegant appearance. It is seldom, except in large roofs, that the flanges have any but a single T section; though in all cases the trough or box section, is peculiarly suitable for resisting the strains to which a roof is subjected.

If the trellis system with vertical struts is adopted, the diagonals need only be ties, as in trellis girders; but if a lattice or other triangulated system be used, all the diagonals should be struts, to meet the various lines of pressure to which the arch is exposed. An arched roof generally costs more than a trussed roof, if the expense of abutments is included. But if, by the position or arrangement of the building, abutments already exist, or if for other reasons they have to be provided, then an arched roof may be preferable to one of a trussed form.

We have selected three examples of arched roofs, the first of which is that over the central transept of the Crystal Palace, at Sydenham, England, and is remarkable as being almost the only example which exists of this form of roof. The other two examples comprise one of the solid web or plate type, and the other of the trussed or open web type. This last is the largest trussed roof erected, with the exception of that already described and erected for the Vienna Exhibition. The Crystal Palace roof is shown in general elevation in Fig. 6657. An elevation of a portion of the main rib is in Fig. 6658, and the details in Figs. 6659 to 6673. This roof, which has a span of 120 ft., is very peculiar in its construction. It is an arch of such a depth, that it acts partly as a girder, throwing upon its supporting structure a comparatively small horizontal thrust. The outer and inner outline of the arch is a perfect semicircle, struck from the same centre; and the rib has therefore an equal depth of 8 ft. throughout, the inner radius being 52 ft., the outer one 60 ft. The rib consists of a bottom and top flange, each consisting of two L irons 6 in. × 3½ in., and a ½-in. plate 10 in. wide, having an available sectional area of 9½ sq. in., as shown in Figs. 6659 to 6661. These flanges are throughout the length of rib of equal cross-section, and are connected together by a double lattice-work, made of flat diagonal bars.

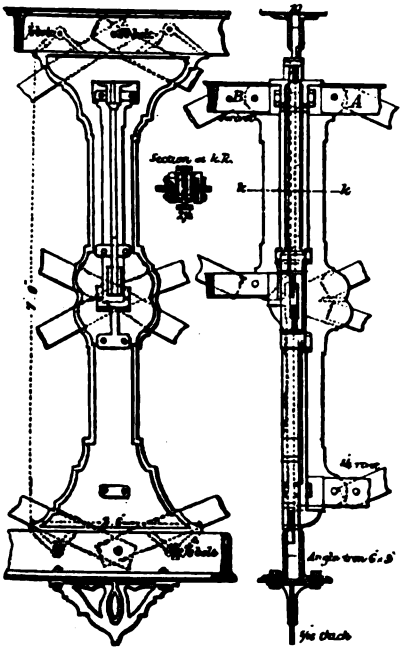
6657.

6658.

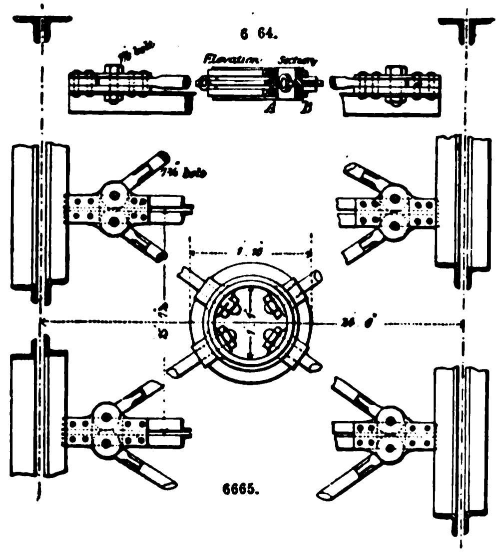


Each side of the rib is divided into eleven equal parts, between its springing and its centre. Each of these parts contains two diagonals, one above the other, and struts radiating to the centre, one of the struts being a cast-iron distance strut carrying purlins and connecting them to main rib, and

6659. 6661. 6660.

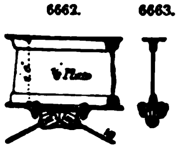


6664.

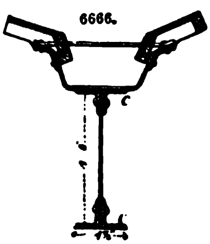


6665.

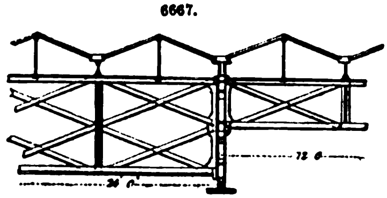
6662. 6663.



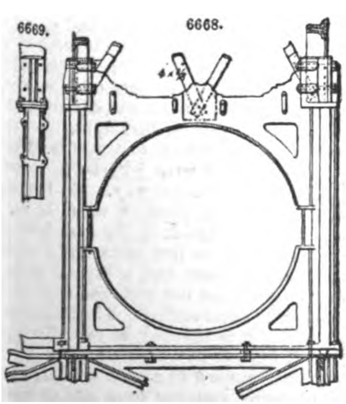
6666.



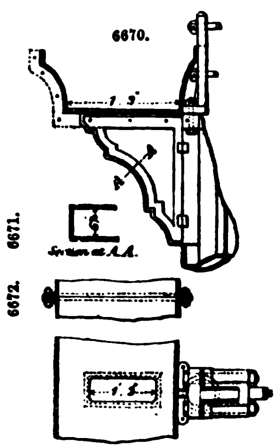
6667.



6669. 6668.



6670.



6671. 6672. 6673.

the other a wrought-iron strut made of two channel irons 4 in. × 1½ in. × ¼ in., having two distance pieces riveted between them. The joints in 6 in. × 3 in. L irons are made alternately at intervals of about 14 ft., proper distance pieces filling out the 3⅝-in. space between L irons, its ¾-in. rivets act

only with single shearing area. At intervals of about 1 ft. 9 in., distance pieces are put between L irons, and fixed also by $\frac{3}{4}$-in. rivets, the same as in wrought-iron struts. The diagonal bars are throughout 4 in. wide, $\frac{3}{8}$ in. thick, with an available sectional area of 1·2 sq. in. running always through two diagonals, and are not straight. But they are, for the sake of architectural appearance, so arranged that they cross exactly in the middle of the rib, and in one-fourth of its depth from its outer and inner outline. They are connected at intersections by a $\frac{3}{4}$-in. rivet. A round ornamental knob, made in two halves, being connected together by three $\frac{3}{8}$-in. tap-screws, covers this joint. The ends of diagonals and wrought-iron struts are connected with the L irons by a $1\frac{1}{8}$-in. bolt, as in Fig. 6659.

The cast-iron distance struts are shaped according to the wrought-iron structure which they have to strengthen, and according to the cast-iron end pieces of purlins which are bolted to them by either six or four $\frac{7}{8}$-in. bolts, as they belong to the 6-ft. or 3-ft. deep purlins respectively.

The strut has accordingly a cross-section of 7 sq. in. sectional area; its $\frac{5}{8}$-in. web is widened out to a pocket for letting the diagonals through, intersecting at this point. The web at top and bottom of strut is brought out to two lugs, which fit with a washer between the two angle irons, and are each bolted to same by one $1\frac{1}{2}$-in. bolt. Proper bosses are cast on to the web for eight $\frac{1}{2}$-in. bolts connecting purlins to same. Underneath these struts, ornamental pendants of $\frac{5}{16}$-in. metal are screwed on to soffit of rib by four $\frac{1}{2}$-in. bolts. There are two kinds of purlins, A and B in Fig. 6660, one kind being 24 ft. long, 6 ft. deep, and the other 72 ft. long and 3 ft. deep. The first serve for bracing two ribs of one pair together, and the others act as pure purlins between each pair of ribs, that is, they have only to support the intermediate rafters.

The 6-ft. deep purlins consist of a top and bottom flange of two L irons, 3 in. × 2 in. × $\frac{1}{4}$ in., of 2 sq. in. available sectional area; and are connected by wrought-iron struts and double lattice-work. Besides carrying intermediate rafters, they serve as bracing of main ribs for giving them lateral stiffness. The struts are 8 ft. apart, and consist of two T irons, 2 in. × 2 in. × $\frac{1}{4}$ in., with $1\frac{1}{8}$ in. available sectional area, having between them in all cases two diagonals, one above the other, similar to the lattice-work in main rib. The diagonals are flat bars, 3 in. wide, $\frac{5}{16}$ in. thick. They are straight, and run always through two divisions of 8 ft. At their ends, proper cast-iron distance struts are fastened to L irons by one $1\frac{1}{8}$-in. bolt, and the web is again properly widened out to a pocket for receiving the ends of two diagonal bars, which are riveted to the casting by one $\frac{3}{4}$-in. rivet. The 3-ft. deep purlins serve only for carrying the intermediate ribs. They consist of a top flange of two L irons, 4 in. × 2 in. × $\frac{1}{4}$ in., 2·44 available sectional area in centre, and a bottom flange of two flat bars being at the end $4\frac{1}{2}$ in. × $\frac{3}{8}$ in., in centre $4\frac{1}{2}$ in. × $\frac{3}{4}$ in., with 4·68 sq. in. available sectional area. These flanges are connected by vertical struts 8 ft. apart, and diagonal tie-bars decreasing in the three diagonals next to end, from $\frac{11}{16}$ in. in thickness to $\frac{1}{2}$ in. to $\frac{5}{16}$ in. to $\frac{1}{4}$ in. They are respectively fixed to top and bottom flanges by a $1\frac{1}{4}$-in., $1\frac{1}{8}$-in., 1-in., and $\frac{7}{8}$-in. bolt. All the bars are 4 in. wide, the struts are of cast iron of a X cross-section, 2 in. × 2 in. × $\frac{3}{8}$ in., and diagonals of wood are put across the diagonal tie-bars, 4 in. wide, $\frac{3}{4}$ in. thick, and fastened by $\frac{3}{8}$-in. bolts.

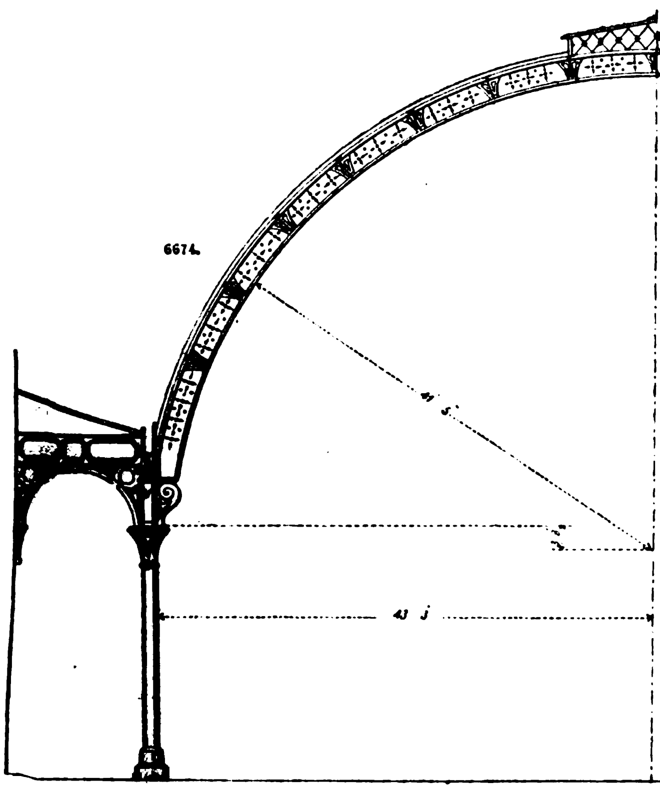
Both purlins carry above each strut an intermediate rafter, Figs. 6662, 6663, having the same outline as the main rib. It is made of a $\frac{1}{8}$-in. web-plate 1 ft. high, in length about 8 ft. 5 in., with a top and bottom flange consisting of two L irons 2 in. × 2 in. × $\frac{1}{4}$ in., in length about 16 ft. 10 in., with $1\frac{1}{2}$ sq. in. available sectional area. A special arrangement is made for bracing purlins sideways to these intermediate ribs. The purlins at the bottom end of their vertical struts are suspended by two rods to points of the intermediate ribs, being just in the middle of two bearings or purlins. For that purpose, a cast-iron shoe is fixed to the bottom L irons of rafter at those points by four $\frac{1}{2}$-in. bolts of a proper shape, to receive the ends of the hanging rods, $\frac{5}{8}$-in. in diameter. The other ends are widened out to an eye, which is connected to the bottom flanges of the 6-ft. or 3-ft. purlins by the bolts, fixing end of vertical strut to the same. The details of this connection are for both purlins the same, except the altered angle of the hanging rods. Next to each of the cast-iron end struts of purlins a kind of pocket is riveted by eight $\frac{3}{4}$-in. rivets, consisting of two $\frac{5}{8}$-in. plates, with two $1\frac{1}{4}$-in. thick distance pieces between them, for receiving the ends of wind-ties. These are flattened out to eyes, and fixed by a $1\frac{1}{2}$-in. bolt. The wind-ties are, throughout, round rods of $1\frac{3}{4}$ in. diameter, and form the diagonal bracing between main ribs, as shown in Figs. 6664, 6665. At the point where they cross each other they are connected by a ring, to which, each end of the four is screwed in the usual way. The ring is in this case of cast iron, and has a sectional area of $9\frac{5}{8}$ sq. in., strengthened by proper bosses round the bolt-holes, and, besides, by two wrought-iron rings of 1 in. sectional area, put on while red hot. This connection serves for bringing a strain on the diagonal bracing rods. The covering of this roof is entirely of glass, on the ridge-and-furrow principle.

The main and intermediate ribs carry wrought-iron gutters, 9 in. wide at the top, 7 in. at bottom, 4 in. deep, shown in Fig. 6666. They are riveted to top L irons of ribs with $\frac{1}{2}$-in. bolts, about 9 in. apart alternately, and to intermediate main ribs with $\frac{3}{8}$-in. bolts in the same way. To the edge of this gutter an L iron $1\frac{1}{2}$ in. × $1\frac{1}{2}$ in. × $\frac{3}{16}$ in. is riveted, and to this a piece of wood $1\frac{1}{4}$ in. × $2\frac{1}{4}$ is fixed by $\frac{3}{8}$-in. screws, about 6 in. apart. Into this piece of wood the ends of the sash-bars are let in, about 1 ft. apart, the top being fixed to the ridge. This miniature roof runs right along the whole rib, from the main gutter to the lower standards of the ventilator, and is hipped at its ends. The main ribs, as well as intermediate ones, carry at their crown, over the cast-iron distance strut next to centre, a lower standard of cast iron 5 ft. $10\frac{1}{2}$ in. high of H cross-section. The sides are filled in with wood, to which the lower plates are fixed. The ventilator is covered, as the other parts of roof, by a number of similar small hipped roofs, Fig. 6667, formed by mere slanting sash-bars, having in this case only wooden gutters, each supported by the standard in centre of each rib. The outer standards of the ventilator are held up by a diagonal bracing running from one to the other, and consisting of $\frac{3}{4}$-in. round rods, which pass through a slotted hole, spaced out in the middle one. A wrought-iron gutter runs along the base of the outer standards, supported by wood boarding, for conducting the water, which drops down from the ventilator covering to the gutters on top ribs. The main rib weighs 10 tons. The purlins, which are 6 ft. deep, weigh each 12 cwt., those 3 ft. deep weigh each 1 ton 4 cwt. The total ironwork in one bay of 86 ft. weighs 61 tons 3 cwt. Each of the main ribs is supported by two columns 8 ft. apart, so that each of the flanges starts over one of the

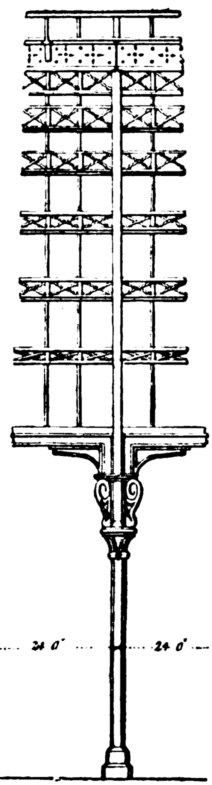
columns. This is effected by means of a cast-iron square frame 8 ft. 8 in. wide and 8 ft. high, shown in Figs. 6668, 6669, bolted to top of each column by four 1-in. bolts, and also by four 1-in. bolts to top of girder connecting top of columns. It consists of two pieces of the same section as the columns, connected by a $\frac{5}{8}$-in. web with a large circular hole taken out in the middle, and smaller ones in the corners. Proper flanges are cast on the top corners of it, to which each of the flanges is bolted by six $1\frac{1}{4}$-in. bolts, by means of a strong bracket. The cross-sections of this frame, through the weakest part of the columns, has $25\frac{5}{8}$ in. sectional area, the octagon columns being 8 in. in diameter and 1 in. thick, the web and its flanges $\frac{5}{8}$ in. thick. The parts of frame acting as bracing to the angles have 9 in. sectional area. Appropriate pockets for receiving the ends of the diagonals are constructed in the upper end of web, the outline of which is shaped like that of the cast-iron distance struts. The two diagonals in the middle are fixed to it by one $1\frac{1}{4}$-in. bolt, and the diagonals at the springing of flanges by one 1-in. bolt each. On top of the outer column of frame, lugs are provided for fixing brackets of $6\frac{1}{4}$ in. inner width under the water outlets of main gutter by four 2-in. bolts, with 1 ft. 2 in. × 5 in. water-way. The main gutter, shown in Figs. 6670 to 6673, running along the whole roof is, on the average, 1 ft. 9 in. wide and 11 in. high. It is cast in lengths of 7 ft. $11\frac{1}{4}$ in., $\frac{7}{16}$ in. thick, the joints being made by eleven $\frac{5}{8}$-in. bolts. The intermediate ribs are supported by cast-iron standards 8 ft. high, resting on one of the cast-iron girders 3 ft. deep and 23 ft. $3\frac{1}{4}$ in. long, which serve in the whole building as bracing and floor, and also carry girders between columns 24 ft. apart. Such girders also brace the columns lengthways under the flanges of main rib. The before-mentioned standards have the section of half a column of 9 in. diameter, are of $\frac{1}{2}$-in. metal, and widened out at the top to a bracket, on which the base of intermediate rib is bolted by six $\frac{1}{2}$-in. bolts. The lowest of the purlins connected to the top of the frame for supporting main rib is also connected by four $\frac{1}{2}$-in. bolts to this bracket, and proper lugs are cast on the top of standard for fixing a bracket, by four $\frac{5}{8}$-in. bolts supporting main gutter at each 8 ft. The horizontal thrust of the main ribs is transmitted by the cast-iron frame to the system of columns, which are connected by cast-iron girders as described before, and well braced by diagonals fixed to ends of girders by means of keys.

At the intersection of vertical diagonals, a similar adjusting connection with a ring and screws, as that for wind-ties, is applied, the whole being hidden by an ornamental joint cover. The entire supporting structure up to the frame is very rigid. It is besides heavily loaded by bearing girders below floor level, and on one side by a fireproof flooring of brick arches, and on the other side by cast-iron girders fastened to brick foundations, and can take easily the thrust arising more from wind pressure than from the weight of the roof, which is taken partly by the rib itself, which is of a very great depth. The rain-water is carried off in the usual way by the hollow columns.

6674.



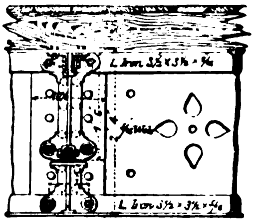
6675.



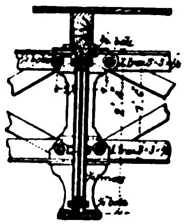
Arched Roof of the Derby Market Hall.—The area covered by this roof is a rectangle 192 ft. long and 86 ft. 6 in. wide, and shown in elevation and section in Figs. 6674, 6675. It is divided into eight

bays of 24 ft. each. The roof is hipped at both ends, and therefore there are only five ordinary principals of 81 ft. 5 in. clear span. The principals consist of wrought-iron arched ribs, the inner and outer curves being true circles struck from the same centre, with radii of 43 ft. 9 in. and 41 ft. 5 in. respectively, the springing of rib being 7 ft. 6 in. above centre. The height of rib at crown is 62 ft. 10 in. above the floor level. The wrought-iron rib is of the same depth throughout, and consists of $\frac{5}{16}$-in. web, and top and bottom flanges each of two L irons $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{16}$. An elevation of a portion to an enlarged scale is shown in Figs. 6676 to 6681.

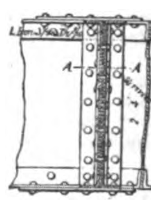
6676.



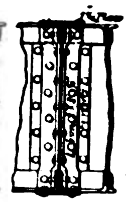
6677.



6678.

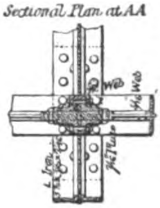


6679.



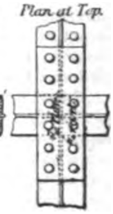
6680.

Sectional Plan at AA



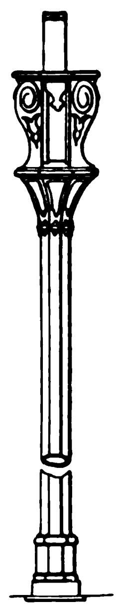
6681

Plan at Top



At every alternate supporting place of the purlins the web is joined by means of a joint plate 1 ft. 9 in. × $10\frac{1}{2}$ in., $\frac{1}{2}$ in. thick, which plate is also riveted on to the web at the other purlins as a strengthening plate. Angle irons extend always over two lengths of web. The web is ornamented in an original way. A neat design of holes is punched out of the solid plate, leaving the material intact where it acts in a similar manner to diagonals, Fig. 6676. These holes, of which the larger are about 6 in. in diameter, were punched out by a simple screw press, with long levers and heavy weights attached to them. When brought once into the swing, the mere momentum suffices to drive the punch through the plate, which is $\frac{5}{16}$ in. thick. The base of rib is horizontal, 2 ft. long, while the top flange is 2 ft. 5 in. above, carried vertically down. It is fixed by eight 1-in. bolts, on each side of the web, to the supporting cast-iron column, the angle irons of the bottom flange being carried round horizontally for that purpose. Riveting is done throughout with $\frac{3}{4}$-in. rivets, about 4 in. pitch. A board $8\frac{3}{4}$ in. wide by 1 in. is fixed to soffit of rib for mere appearance. The rib carries wrought-iron lattice purlins, at intervals of 6 ft. 9 in. On each side of such purlin a cast-iron strut is fixed to the rib and purlin by six $\frac{3}{4}$-in. bolts. By this connection, the projecting of the purlins beyond the ribs is prevented.

6682.



The purlins, which are 23 ft. 10 in. long and 1 ft. 6 in. deep, Fig. 6677, are radial, and are connected to the main ribs by means of the cast-iron end struts of $\frac{5}{8}$-in. metal by two $\frac{3}{4}$-in. bolts. They consist of a simple truss, the top and bottom flange of which are each formed by two L irons 3 × $3\frac{3}{8}$ in. The top flange is also connected by $\frac{3}{4}$-in. bolts to top flange of main rib. Cast-iron struts, 3 ft. pitch, and flat bar diagonal bracing $2\frac{1}{2}$ in. wide, increasing from $\frac{1}{4}$ in. to $\frac{5}{8}$ in., and $\frac{1}{2}$ in. in thickness, connect the flanges of the truss by $\frac{3}{4}$-in. bolts, serving as pins for diagonals. Wooden diagonals are also used for giving the appearance of a complete diagonal truss. The purlins support at each strut a wood rafter 6 in. in depth. Each alternate strut is so enlarged as to form brackets connected to the wood rafters by $\frac{5}{8}$-in. bolts, which are employed to keep the purlins in their radiating position. The other struts are brought out at the top to more lugs fixed to rafters by $\frac{3}{8}$-in. coach screws.

On the top of the main ribs a piece of wood $5\frac{1}{2}$ in. × 3 in. is fixed for nailing the 1-in. boarding thereto. The 1-in. boarding is covered by Italian zinc near the crown, and at the lower part by slates. A portion of the roof is glazed. The ends of the roof, it being hipped, are formed by ribs which are generally constructed like the ordinary ones, but stronger in cross-section. One ordinary rib weighs $5\frac{1}{4}$ tons. The weight of purlins, and standards for one bay, is $9\frac{1}{2}$ tons.

The ironwork for one bay of roof weighs $14\frac{3}{4}$ tons.

Each rib is supported by a cast-iron column, see Fig. 6682, 23 ft. high from floor, level to bottom of gutter, of an octagon section, and $1\frac{1}{4}$ in. thickness of metal. The base is also octagonal, 2 ft. 10 in. high, and at the bottom of 2 ft. inscribed diameter. At a height of 19 ft. 7 in. from floor level it widens out into an octagon capital of 2 ft. 9 in. inscribed diameter at the top. The base is plain. The top is a little ornamented by raised leaves. Above that, the column widens out into a kind of flat box, 4 ft. 2 in. high, with a bracket in front, supporting the horizontal plate to which the L irons of base of columns are bolted. The horizontal plate extends over the middle of the continued column, leaving on each side of bracket openings for receiving outlets of gutters. The column changes above this horizontal plate into a vertical piece of H section, 1 ft. × $10\frac{1}{2}$ in. × $7\frac{3}{4}$ in. × $1\frac{1}{4}$ in., 4 ft. × 4 in. high. The vertical part of the base of rib is bolted, as already mentioned, to the inner flange, $10\frac{1}{2}$ in. wide. The bracket in front appears as an ornamental bracket, of the same thickness as the flat box forming part of column, which is in elevation shaped like the two brackets supporting the outlets of gutter on each side of column, supporting outlets and the upper flange of the H iron, a frame 11 ft. 6 in. long

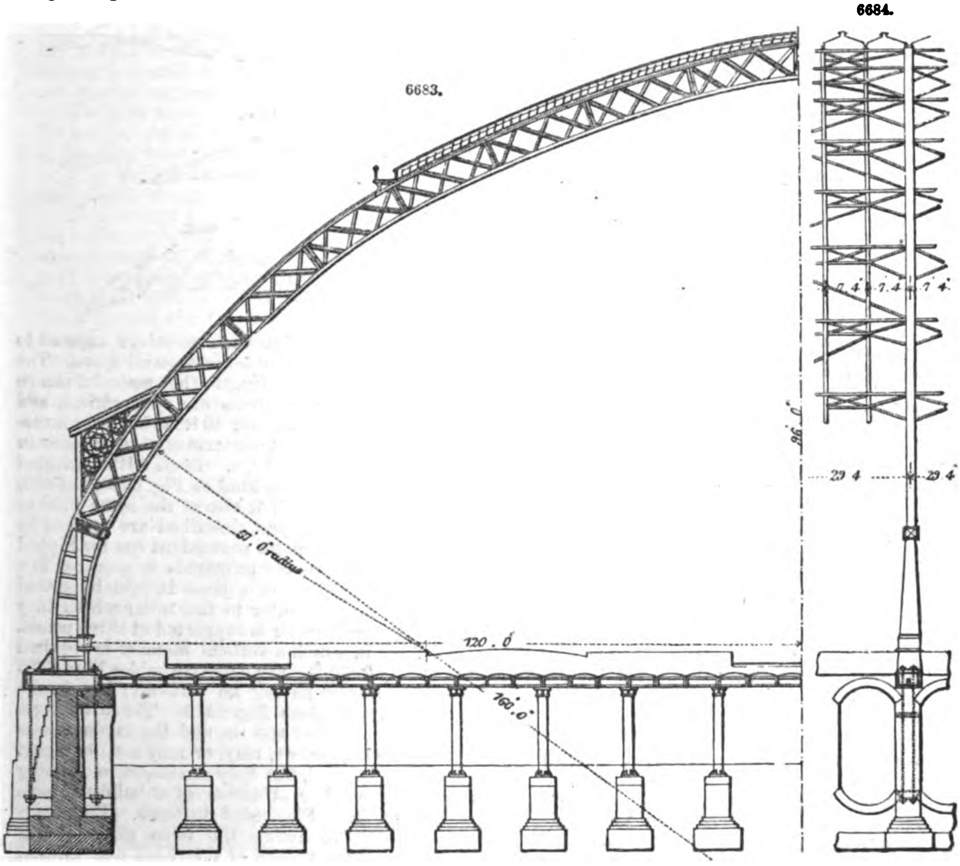
is fixed by six 1-in. bolts. It consists of an arch of 5 ft. 1 in. radius of bottom outline, and on the top a square frame 2 ft. 6 in. deep. All the main flanges are 8 in. wide ⅝ in. thick, only the upper flange of frame 1 ft. wide × ⅝ in., the web being ½ in. thick.

The other end of the frame is suitably provided with a vertical flange and a lug at the bottom, for resting on the wall, being besides bolted to it by four 1-in. bolts. The horizontal thrust is in this roof taken by a very peculiar arrangement. On the top of the frames just described, on each end strong boxes are cast on, each of which contains a pin dropped into it from above. These pins connect the ends of diagonal bracing rods, with eyes on one end and key adjustment at the other. Along the outer boxes a wrought-iron flange runs throughout the length of the building. This flange, consisting of four plates 1 ft. × 1½ in., and two L irons 3 ft. × 3 ft. × ½ in. in centre, is connected by the pins to the diagonals. On the other hand, the gutter acts as the other flange of this horizontal girder, and is made sufficiently strong, being 1⅜ in. thick. The single lengths of gutters are connected together by means of eight 2-in. bolts, being equal in sectional area to the strength of the gutter, of course piercing the web of the T-shaped part of column.

As the gutter is sometimes exposed to tensile strains, it requires therefore the above-mentioned area. There are eight diagonals, one for each bay, and the dimensions of the rods increase from the centre towards the ends. This roof offers in its longitudinal direction so great a resistance to the force of the wind that wind-ties are unnecessary. The gutter, which is 1 ft. × 5½ in. deep, 1 ft. wide, and 23½ ft. × 4 in. long, and 1⅜ in. thick, has at distances of 3 ft. small shoes cast on, which receive the ends of the intermediate rafters, 6 in. × 3 in. The rafters are placed across the 12-ft. corridor at a proper slope, laid with 1-in. boarding and covered with slates. The other ends of these rafters rest on shoes on the wall surrounding the hall. The gutter is covered by a snow grating, which is 1 ft. × 3 in. wide, and cast in lengths of 6 ft. It rests on small supports fixed by two ⅝-in. bolts to cross-pieces cast on the gutter at every second pair of shoes, and serving as distance pieces in the casting while it cools and prevents it from warping. These distance pieces must always be made with a top flange, otherwise the other parts of castings prove stronger in shrinking, and tear it in the middle. The rain-water is carried sideways by the bracket-shaped outlets of gutters into the column, and carried off to the drain pipes. The cast and wrought iron work of one bay of roof weighs 14⅝ tons. The cast and wrought iron work of one bay of supporting structure weighs 17⅝ tons.

6684.

6683.



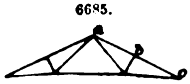
Roof of the St. Pancras Station, Midland Railway, London.—The area covered by this roof, which is 240 ft. in span, is 690 ft. by 240 ft. It is shown in Figs. 6683, 6684. The main ribs are 29 ft. 4 in.

from centre to centre, and have three intermediate ribs between them at equal distances apart, carried at every 18 ft. 6 in. by trussed purlins between the main ribs. The form of the ribs is entirely novel. They spring directly from the ground, and are firmly connected to massive brick piers below the floor level. The curve of the ribs is of two radii of 160 ft. and 57 ft., meeting at an angle in the centre 100 ft. above the level of rails. The ribs are 6 ft. deep, and formed with open box flanges 10½ in. deep; the flanges being braced together by diagonal channel irons and radial struts forming the ends of the purlins. The lower parts of the ribs, to a height of about 25 ft. from platform level, are constructed of plates and angle irons riveted together. The intermediate ribs are 10½ in. deep, and consist of angle irons braced with diagonal bars. The purlins are braced beams 18 ft. 6 in. apart. They are so constructed that they stiffen the main ribs laterally. The bracing is so arranged as to carry the proper proportion of each of the three intermediate ribs, besides assisting to keep the bottom flanges of the main ribs in place. The whole of the roof is braced horizontally to resist any strains that may be caused by the pressure of the wind either on the gable or on the side.

This roof virtually springs from the ground, the side walls being merely screens to hide the springings. The main ribs are tied underneath the platform by a system of wrought-iron girders for the purpose of counteracting the outward thrust which is common to arched roofs. This principle of providing for the horizontal thrust of large roofs of this description, has been successfully applied in other instances. When iron girders are thus employed, they not only serve the purpose of supporting a platform alone, but they can be made to cover a certain number of spans or intervals below, and the space thus obtained is utilized as vaults and cellars.

Trussed Roofs.—All the principals belonging to the second class are essentially girders or trusses, and consist of a top member which is in compression, a bottom member which is in tension, and various struts and ties arranged within the space between the two, to support the top member and the load at intermediate points, and to transmit the strains produced at these points to the end supports. Instead of attempting to divide into classes, according to their characteristic features, the innumerable forms adopted for trussed principals—a task hardly possible when it is considered how one system is mixed with another—a few forms have been selected which, directly or indirectly, will include most of the varieties which exist. The different kinds are shown in Figs. 6685 to 6693, and in

6685.



6686.

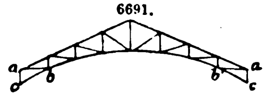
6687.

6688.

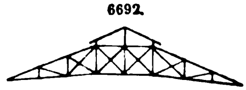
6689.

6690.

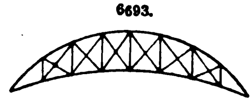
6691.



6692.



6693.

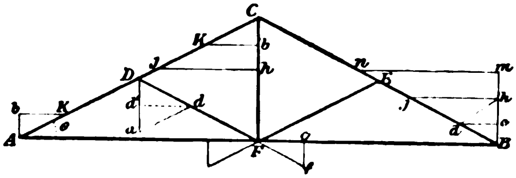


each case the thick lines represent compressive members, and the thin lines members exposed to tension. Fig. 6685 is of the simplest kind, and is equally serviceable for large or small spans. The short struts are often made of cast iron, and owing to their moderate length, this material can be safely and economically applied without excessive weight. The connections are symmetrical, and have a natural, unconstrained appearance. For the larger spans, those over 40 ft., it becomes necessary to construct the two upper rafters as girders to resist considerable transverse strains, because in a roof of such a size there must be purlins between the points *a*, *b* and *b*, *c*. Roofs with this kind of principals are sometimes called French roofs. Fig. 6686 is of the same kind as Fig. 6685, but with the strut so placed as to support the rafter in two points. Fig. 6687 is also of the same kind as Fig. 6685, but with longer rafters doubly trussed. The three forms just described are marked by the absence of vertical members, and for this reason the system is not a convenient one for hipped roofs, and for those roofs also where a longitudinal bracing between the principals is required in a vertical plane. Fig. 6688 may be considered as the elementary form of a class in which vertical members are introduced, and in which the struts are not perpendicular to the rafter which they support. The same system is carried out in Fig. 6689, where each rafter is supported at three points. This kind of truss is most commonly used for hipped roofs in which a vertical member is required at the junction of the hipped part. It is applied to spans up to 60 ft. Fig. 6690 resembles Figs. 6685 to 6687 in having the struts perpendicular to the rafters, and in having no verticals; but in the general arrangement of the parts and of the connections it resembles Fig. 6689. The advantages which this form of truss, Fig. 6691, affords are, the curved shape of the tie, and the favourable or large angle of the tie at its start, which is at *a*. The parts *a c*, and *c b*, may, or may not, form part of the truss, which is complete without them, between *a b*, *b b'*, *b' a'*, but they are useful as forming bracing with the columns or walls, thus rendering the complete structure of a building more rigid and self-contained than with any of the roof forms from Figs. 6685 to 6690. The designation of roof trusses is applied to forms in Figs. 6685 to 6692; the term girder being seldom used, although there is no important difference between trusses of this kind and girders. Fig. 6692 is sometimes used when the roof covering must be interrupted to admit of ventilation. In its construction it resembles even more than do the preceding forms an ordinary girder, and there is nothing special to remark in it. Fig. 6693, which from its shape may be called a sickle girder, has

lost almost all traces of a roof truss, and in detail is constructed very much like a bow-string girder with a top member to resist compression, and the bottom member a simple tie. The space between the two members is occupied by bracing, which is of a light nature, and may be of the character shown in Fig. 6693, if the ends are not hipped. In all trussed roofs the divisions of the rafter and the distance apart of the struts must be arranged to suit the kind of covering adopted.

Strains upon Trussed Roofs, Simplest Form.—The simplest case is that represented in Fig. 6694, and the strain upon the different members will be ascertained and tabulated. It is an ordinary king-roof principal, and answers well for small spans. In the figure the span is 20 ft., the rise 5 ft., and the total weight upon the whole principal is taken equal to 2 tons, so that 1 ton will be the load distributed over one-half of it. The same conditions will be assumed with respect to roofs as have been already laid down for bridges, and it will be always considered that the component parts of the structure are strained only in the direction of their length. The component parts of all the examples of roofs which will be investigated will be assumed to be unacted upon by any other strains except those already mentioned, and will virtually be secured against their influence, either by their short length, bracing, or form of section. Before proceeding to the graphical analysis of the strains upon the diagram, the first step is to ascertain the manner in which the load is distributed. With 1 ton upon the half truss there will be 0·25 ton supported directly at A, by the reaction of the supports, and will practically exert no effect upon any part of the principal; 0·25 ton at the apex C, which is resisted by the counteraction of 0·25 ton, due to the load upon the other half of the truss, making in all 0·5 ton at the point C, and 0·25 + 0·25 = 0·5 at the point D. As we are only considering half the principal, the load at the apex C will be taken equal to 0·25 ton, or one-half of that which is supported at that point by the joint action of the two rafters. The distribution therefore will be as follows;—A quarter of a ton at A and C, and half a ton at D. Sometimes the whole load on one rafter is considered to be equally divided among all the points of supports, in which case there would be one-third of a ton at A, D, and C. The former method is to be preferred as the more accurate, and it will always be adhered to in all similar instances. Moreover, in making the assumption that the weight is equally distributed, there is a larger portion borne directly by the support at A than upon the former supposition; and as this is considered to exert no strain upon the truss, it should evidently be kept as small as possible. Let us now examine in detail the action of the weight of the several points upon the rafter, and determine the strains they give rise to in the various parts of the demi-truss.

6694.



The weight at A is resisted directly by the vertical reaction of the wall, and consequently produces no strain upon any part of the principal, so that we may pass on to that at D.

This weight of 0·5 ton is in the first instance supported by the resistance of the lower part of the rafter A D, and that of the strut D F, causing strains of compression in both of them. Their amount may be readily determined. Make D *a* by scale equal to 0·5 ton; draw *a d* parallel to A D to meet the strut D F, and *a d* will equal the strain upon A D, and D *d* that upon D F. The strain A D upon the rafter is transferred to the point A, where it is resisted by the action of the tie-rod A F, and the vertical reaction of the support at A. Making A K equal to *a d*, and drawing K *b* parallel to the tie-rod—that is, horizontal, to meet the vertical line A *b*—the strain upon the tie-rod A F is equal to *b* K. These, however, are not the only strains brought upon the part A D of the rafter and the tie-rod A F by the action of the weight at D, as will be apparent on proceeding to examine into the effect of the strain D *d* upon the strut D F. The compressive strain D *d* is transferred to the point F, where it is resisted by the bars A F and F C. Plotting F *f* equal to D *d*, on the prolongation of the strut D F, and drawing *f c* parallel to F C, the strains upon A F and F C are represented by F *f* and F *c*. The strain upon A F may be disregarded, as it is counterbalanced by one of an opposite tendency and equal in amount from the weight at E, which also brings another equal strain upon the king-rod. The total strain upon the king-rod is equal to 2 × *f c*, but only half of this has to be regarded as affecting the other members of the half truss. Following the action of the strain *f c*, it is transferred to the point C, where it is represented by C *b*. If *b f* be drawn parallel to the tie-rod A F, then C K will represent the strain upon the part C D of the rafter. This strain is again transferred to the point of support A, thereby causing an additional strain upon the lower part of the rafter A D, and upon the tie-rod A F. So far, therefore, the total strain upon A D is equal to A K × C K = 2 A K, and that upon A F to 2 *b* K. In this instance the separate strains upon each member of the principal are equal, but this is partly due to the manner in which the load is distributed, the ratio between the span and rise of the roof, and the horizontality of the tie-rod, as will be more fully perceived in checking the strains by mathematical analysis. The whole action of the weight at D has now been accounted for, and it remains to examine into that of the apex C. This, by the distribution of the load, is equal to 0·25 ton, and, upon the scale of strains, equal to C *b*. Its action is therefore identical with that already considered, and it impresses upon the rafter an additional strain equal to C K upon C D and upon A D, and consequently an additional strain equal to *b* K upon the horizontal tie-rod. Instead of taking the last two strains separately, they might have been made equal to C *h*, and consequently *c j* and *h j* would have represented the result upon the two parts of the rafter and the tie-rod, being each of them respectively equal to 2 C K and 2 *b* K. A reference to the diagram will indicate that the strains may be arrived at in a somewhat different manner, by resolving the forces as shown at B. If these be compared, with those already determined, the identity will be established. The strains may now be tabulated as represented in Table II., and may be briefly

summed up as follows;—Strain upon A D = + 3 A K; upon D C = + 2 C K = C j; upon A F = − 3 b K; upon C F = − 2 f c; and upon D F = + D d.

There is clearly some analogy in the action of the strains upon a trussed roof and those upon a girder. In both instances they are augmentative, according to the number of separate parts or bars in the structure, but the direction in which the increase takes place is not the same. Thus in a horizontal girder the strain upon the flanges increases towards the centre, but in a roof they increase towards the abutments, the lower end of the rafter having to resist the maximum strain. A similar increase attends the strains upon the tie-rod, as will be pointed out when examples are treated of, in which the tie-rod consists of two or more separate bars. If the rafter C B be considered in the light of the last, or end bar, of a lattice of a Warren girder, the total strain upon the lower portion may be arrived at in exactly the same manner as in that case. The total reaction at B is equal to 1 ton, but of this one quarter is directly supported by the wall, so that the portion affecting the rafter is reduced to 0·75 ton. Making B m = 0·75 ton, and drawing $m\,n$ parallel to the tie-rod, we obtain B n, equal to the total strain upon E B, and $m\,n$ equal the total pull upon the tie-rod. It has been assumed in this investigation that there is no weight, such as a floor, for instance, placed upon the tie-rod, but if such should be the case, it should be distributed between the three points of support A, F, and B, and the weight added to the strain already obtained on F C. The result will be an increase on all the strains with the exception of that upon the struts D F and F E, In this particular description of iron structures there is very rarely any permanent load upon the tie-rod. During the erection of the roof, and at the subsequent periods of repair, the tie-rod is subjected to a small permanent load, consisting of the necessary scaffolding and workmen, but this is not of sufficient importance to be taken into the calculation, as the margin allowed for safety will more than cover it.

Where there are so few parts, as in the first example we have selected in the diagram, all the strains may be readily calculated by a few simple equations, directly the theory of their action is understood, that is, provided their effect upon the various members of the truss can be traced from their origin to their final resistance at the points of support. Let W represent the total weight upon one half of the truss, then there will be a weight of $\frac{W}{2}$, situated at the point D, and of $\frac{W}{4}$ at A and C. The strain upon the end of the rafter, resulting from the weight $\frac{W}{2}$, is equal to $a\,d$, and by construction $a\,d = d$D. Drawing $d\,d'$ parallel to the tie-rod, $d\,d' = d'$ D $= \frac{W}{4}$ and angle $a\,d\,d' = \theta$. Putting $a\,d$ = S = strain on A D, we have $S = \frac{W}{4 \text{ sine } \theta} = \frac{W}{4}$ cosec. θ. To find the value of θ, we put tang. $\theta = \frac{CF}{AF} = \frac{5}{10} = 0{\cdot}5000$ and θ = practically 26° 34′. Tracing the action of the weight $\frac{W}{4}$, which is the vertical component of that already determined, it will be seen that it is transferred to the apex C, and again resolved into a thrust upon the rafter.

Summing up, therefore, we have the total strain upon the lower part of the rafter equal to these three, and therefore $S = \left\{\frac{W}{4} + \frac{W}{4} + \frac{W}{4}\right\} \times \text{cosec. } \theta = \frac{3\,W \times \text{cosec. } \theta}{4} = 0{\cdot}75 \times \text{cosec. } \theta$. But cosec. $\theta = \frac{1}{\text{sine } \theta}$, then S = 0·75 × 2·234 = 1·67 ton, which agrees with the result given in Table II. The total tensile strain or pull upon the tie is the strain which resists this thrust on the rafter, and is consequently its horizontal component, and is represented by $m\,n$ in the diagram. By construction, the angle $m\,n$ B equals the angle θ, and putting S^1 for the pull on the tie we obtain $S^1 = S \times$ cosine θ. From above S = 0·75 × cosec. θ; therefore

$$S^1 = 0{\cdot}75 \times \text{cosec. } \theta \times \text{cosine } \theta = 0{\cdot}75 \times \text{cotang. } \theta = 0{\cdot}75 \times 2 = 1{\cdot}50 \text{ ton.}$$

Obviously the thrust upon C D equals that upon A D, minus $a\,d$, therefore equals

$$S - (0{\cdot}25 \times \text{cosec. } \theta).$$

The strain upon the strut D F = $a\,d$, and needs no further elucidation. It only remains therefore to calculate that upon the king-rod. This is equal to 2 $f\,c$. Let it be put equal to S^2, and we shall have the equation $S^2 = 2$ F f = 2 D d = 2 $a\,d$ × sine θ. But $a\,d$ = 0·25 × cosec. θ, therefore $S^2 = 2 \times 0{\cdot}25 \times$ cosec. $\theta \times$ sine $\theta = 2 \times 0{\cdot}25$ ton. This completes the calculation of the strains upon the half truss. It must not be forgotten that a horizontal thrust is generated at the apex C, which is resisted by one similar in amount and direction, due to the action of the load upon the remaining half of the principal. This would be rendered apparent if the other half of the truss were replaced by a wall. As some of our readers may not be acquainted with trigonometrical calculations, the following equations will enable them to check some of these strains they have determined by the aid of the diagram by simple arithmetical means. The rule for the total strain upon the end of the rafter may be thus expressed; the total strain upon the end of the rafter is equal to the total weight supported by it, multiplied by the length of the rafter, and divided by the rise of the roof. The rise of the roof is the distance from the middle part of the tie to the apex or junction of the rafters. If P be the length of the rafter, L the half span, and R the rise, then $P^2 = L^2 + R^2$ and $P = \sqrt{L^2 + R^2} = \sqrt{100 + 25} = 11{\cdot}18$.

Substituting these values in the rule, the strain upon the end of the rafter equals

$$\frac{0{\cdot}75 \times 11{\cdot}18}{5} = 1{\cdot}67 \text{ ton,}$$

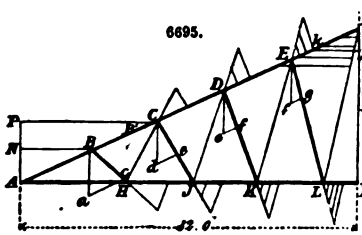
as before. Since the total strain upon the tie-rod is the horizontal component of this, the rule for it is, the total strain upon the tie-rod is equal to the total weight upon the rafter multiplied by the half length of the tie, and divided by the rise. Consequently in the present case it is equal to $\frac{0 \cdot 75 \times 10}{5} = 1 \cdot 50$ ton, as in Table II. Similarly to a girder, the strains upon a roof principal are increased in the ratio of the span, and diminished in the inverse ratio of the rise, which is virtually the depth, and exercises the same influence over both examples of construction.

TABLE II.

Weight at	Parts of the Half Truss.				
	A D.	D C.	A F.	C F.	D F.
A	+0·55	+0·55	−0·50	−0·25	+0·55
D	+0·55	..	−0·50	..	..
C	+0·55	+0·55	−0·50	..	..
E	..	..	..	−0·25	..
Total	+1·65	+1·10	−1·50	−0·50	+0·55

Single Roof Truss with Diagonal Bracing.—It has been already mentioned that the tie-rod of a roof truss is usually placed in an inclined position. Before proceeding to analyze an example of that description, we will investigate the one illustrated in Fig. 6695, in which the span, rise, and rate of loading are identical with those adopted in the example on p. 2811. The difference consists in the manner in which the bracing is arranged, and the two examples should be carefully studied and compared together, so that an accurate estimate may be formed of their relative advantages. In the diagram, Fig. 6695, the struts approach nearer to a perpendicular position with respect to the rafter, while the tie or queen-rods are no longer vertical, but inclined at different angles to the horizontal. This description of bracing, allowing for the varying angles of inclination, is similar to that of a Warren truss or girder, and it is preferable to the older form represented in Fig. 6689. The majority of the struts in the latter instance are shorter than the corresponding ones in the former figure, and are consequently not strained to quite the same amount. This difference would be shown more conclusively if, instead of the unit weight selected for the purpose, the actual weight likely to be placed upon a roof of the given dimensions had been adopted. The former, however, possesses the advantage of acting as a standard for all similarly trussed roofs of the same span and rise, since, to find the actual strains upon the various parts, it is sufficient to multiply the strains given in Tables I. and II. by the proper constant, or the number representing the ratio between the unit adopted and the load in question. In the present example the strains are divided into two classes, under the heads of direct and transmitted strains. So that it will be perceived how the action of the same weight is multiplied, again and again, by the different parts of the bracing. It is of very little use to be acquainted with the total strain on any particular bar, unless the designer of a structure is capable of analyzing that strain, dividing, and, as it were, dissecting it into every one of its component parts. Mathematical formulæ, wherever they are applicable, suffice for calculating the total amount of any strain, but they do not afford the slightest clue to the manner in which it has been gradually and successively accumulated. They give, it is true, the result of a load, but impart no information respecting its intermediate action. As an instance, take the formula for the strain upon the last bar of a Warren girder, where S equals the strain, W the total load, and θ the angle of inclination of the bars to the horizon. The calculation is at once made by the equation $S = \frac{W \times \text{cosec.}\ \theta}{2}$; but the equation affords not the slightest information respecting the manner in which the successive strains are obtained, until they reach the total represented by S.

6695.



The direct strains result from the action of those portions of the total load situated at the points B, C, D, E, and F, and affect the several bars of the rafter and the inclined struts attached to them. It will not be necessary to do more than to indicate briefly the effect of the strains, represented by the lines of the diagram, as the principles of the analysis and the geometrical reasoning have already been enunciated. Moreover, Table III. has been constructed to show at a glance the direct strains resulting from the weights placed at the different apices of the triangles. The distribution of the load will be the same as before; therefore, making the vertical lines B a, C d, D e, E f, respectively equal to 0·2 ton, the direct strains upon the rafter and struts are given by the other sides of the triangles, and will be found to agree with those in Table III.

At the apex F the weight is only half that situated at the lower apices; so that F j = 0·1, and F k equals the strain upon the part of the rafter E F, and is also added to those already obtained for the other parts. It might, perhaps, be considered that the addition of the strain upon B C, or upon any other bar of the rafter to that upon A B, should be regarded as a transmitted strain, and not a direct one. So it would, were the direction of the strain altered, but it is not. Both the direction and nature of the strain remain constant, and, moreover, A B, B C, and, in fact, all the separate

bars of the rafter A F, are in reality but one bar, although theoretically subdivided. This is clearly not the case with the strain induced upon the bar H C by the action of the weight at B. The compressive strain in the strut B H is changed both in direction and character when transmitted to the bar H C or A H; but the strain upon the bar B C from the weight at C undergoes no change of any kind in amount, character, or direction in passing to the bar A B. It is a simple addition, and so for the other strains transferred from C D, D E, and E F.

TABLE III.

Parts of the Half Truss.	Direct Weights at					Total Strains.	
	B.	C.	D.	E.	F.		
A B	+0·165	+0·0975	+0·0675	+0·055	+0·245	+0·630	Rafter.
B C	..	+0·0975	+0·0675	+0·055	+0·245	+0·465	
C D	..	..	+0·0675	+0·055	+0·245	+0·367	
D E	..	..	..	+0·055	+0·245	+0·300	
E F	..	..	..	..	+0·245	+0·245	
B H	+0·200	..	..	..	..	+0.200	Struts.
C J	..	+0·185	..	..	..	+0·185	
D K	..	..	+0·182	..	..	+0·182	
E L	..	..	..	+0·185	..	+0·185	

There is no readier method of ascertaining the strains in Table III., than that demonstrated in the diagram. In consequence of the inclination of the bars and their deviation from the vertical, the trigonometrical calculation of the thrusts, or compressive strains upon the different parts of the rafter and struts, is not capable of being so easily effected as in the former instance, where the queen-rods were perpendicular, nor is there any advantage to be gained in resorting to that method. The manner in which the half truss is affected by the transmitted strains is represented in Table IV. By the aid of the diagram there will be no difficulty in following the analysis, and there is no point calling for especial notice, with perhaps the exception of the strain upon the centre bar L M of the horizontal tie-rod. This is found equal to − 1·069. It is evident, on inspection, that the bar L M is not in any way affected by the strains upon the intermediate struts and ties, forming the component parts of the truss. The strain upon it is exactly the same as if they were all removed, and the truss consisted simply of a rafter A F and the half tie-rod A M. The total load will then be supported at the two points A and F, half at each point. Make A N equal to this load equal to 0·5 ton, and draw N B parallel to A M. The line N B will scale 1·069, and will represent the strain upon the bar A M, or L M. Whatever form of truss may be adopted, or whatever may be the number of the secondary or subsidiary trusses, the strain upon the centre bar of a horizontal tie-rod will be that due solely to the loading upon the primary truss, and will be altogether unaffected by the introduction of smaller secondary trusses and bracing. This will be better seen in the example of a roof with an inclined tie, as will also several other conditions of strain, which are not so apparent in the simple instance in Fig. 6695. The direct and transmitted strains may now be summed up, and tabulated as shown in Table V.

The sum of the two descriptions of strains represents the total strains resulting from the whole weight of the truss. The strains upon the ends of the rafter and the tie-rods, that is, upon the bars A B and A H, may be checked by plotting the total reaction of the load at the abutment and completing the triangle of forces.

Make A P equal the reaction, draw P P^1 parallel to the horizontal tie, and A P^1 and P P^1 will give the measure of the strains upon A B and A H to the same scale. Or the same results may be obtained by the formula already given, which, however, it must be remembered, only applies to those examples in which the tie-rod is uniformly horizontal. Let S and S^1 equal respectively the strains upon the ends of the rafter and tie-rod, or upon the bars A B and A H. Putting θ for the angle of inclination F A M, and W for the total weight upon the half roof, then $S = W \times \text{cosec.}\ \theta$ and $S^1 = W \times \cot.\ \theta$ and $S = 2{\cdot}124$, and $S^1 = 1{\cdot}929$, which agree with the strains found by summation in Table V. Similarly the strain upon the bar L M of the tie-rod may be found by calculation.

The natural cotangent of 25 degrees being 2·144, the strain required equals $2{\cdot}144 \times 0{\cdot}5 = 1{\cdot}07$ ton. The member which has the greatest influence upon the strains upon a roof is the tie-rod. Directly this becomes inclined from the horizontal, it modifies the amount of the strains in all the component parts of the truss, and it is no longer possible to check the sums of the strains upon the ends of the rafter and the tie-rod by the same simple methods already adopted. This follows from the fact, that if the portion of the tie-rod situated next to the rafter be inclined upwards from the horizontal, while the central portion remains horizontal, there are no longer three forces making equilibrium at the abutment, but four.

One operation is therefore not sufficient to resolve the strains upon all the bars affected by the vertical reaction at that point. It must not be assumed that the process of analysis which answers for a simple example, is also applicable to others of a more complicated and scientific form.

In the practical designing of roofs, if they be thoroughly well secured by wind-ties and bracing from the sudden action of violent strains, the material may be taxed a little more than in the case of a bridge. So far as the parts in tension are concerned, it might be safe to increase the stereotyped 5 tons to 6 tons an inch of sectional area, but it would scarcely be prudent to adopt the same course with the parts in compression. The struts constitute the weak part of a roof truss, and there is, moreover, this important difference between it and a lattice bridge—the failure of one

bar in the former would be certain to seriously jeopardize, and probably destroy, the security of the others. This contingency is a well-known and a well-founded objection against the employment of the Warren girder for any except limited spans, whereas the fracture of one of the bars in the web of a lattice girder would affect that bar only.

TABLE IV.

PARTS OF THE HALF TRUSS.

Weights at	AB.	BC.	CD.	DE.	EF.	AH.	HJ.	JK.	KL.
B	+0·120	+0·120	+0·050	+0·032	+0·095	−0·210	−0·067	−0·030	−0·020
	+0·050	+0·050	+0·032	+0·095	..	−0·067	−0·030	−0·020	−0·073
	+0·032	+0·032	+0·095	..	..	−0·030	−0·020	−0·073	
	+0·095	+0·095	..	..	..	−0·020	−0·073		
	..	..	..	..	..	−0·073			
C	+0·115	+0·115	+0·115	+0·060	+0·200	−0·143	−0·143	−0·070	−0·037
	+0·060	+0·060	+0·060	+0·200	..	−0·070	−0·070	−0·037	−0·160
	+0·200	+0·200	+0·200	..	..	−0·037	−0·037	−0·160	
	..	..	..	..	..	−0·160	−0·160		
D	+0·087	+0·087	+0·087	+0·087	+0·305	−0·120	−0·120	−0·120	−0·073
	+0·305	+0·305	+0·305	+0·305	..	−0·075	−0·073	−0·073	−0·273
	..	..	..	..	..	−0·275	−0·273	−0·273	
E	+0·425	+0·425	+0·425	+0·425	+0·425	−0·090	−0·090	−0·090	−0·090
	..	..	..	..	..	−0·340	−0·340	−0·340	−0·340
F	..	..	..	..	..	−0·223	−0·223	−0·223	−0·223
Total ..	+1·499	+1·499	+1·379	+1·329	+1·297	−1·929	−1·719	−1·509	−1·289

Weights at	LM.	BH.	CJ.	DK.	EL.	HC.	JD.	KE.	LF.
B	−0·073	..	+0·087	+0·050	+0·048	−0·150	−0·070	−0·048	−0·037
C	−0·160	..	..	+0·120	+0·075	..	−0·170	−0·100	−0·075
D	−0·273	..	..	..	+0·148	..	..	−0·180	−0·147
E	−0·340	..	..	..	..	..	..	..	−0·187
F	−0·223								
Total ..	−1·069	..	+0·087	+0·170	+0·271	−0·150	−0·240	−0·338	−0·446

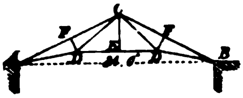
TABLE V.

Parts of the Half Truss.	Direct Strains.	Transmitted Strains.	Total Strains.	
AB	+0·630	+1·499	+2·129	Rafters.
BC	+0·465	+1·499	+1·964	
CD	+0·367	+1·379	+1·746	
DE	+0·300	+1·329	+1·629	
EF	+0·245	+1·297	+1·542	
AH	..	−1·929	−1·929	Tie-rod.
HJ	..	−1·719	−1·719	
JK	..	−1·509	−1·509	
KL	..	−1·289	−1·289	
LM	..	−1·069	−1·069	
BH	+0·200	..	+0·200	Struts.
CJ	+0·185	+0·087	+0·272	
DK	+0·182	+0·170	+0·352	
EL	+0·185	+0·271	+0·456	
HC	..	−0·150	−0·150	Ties or queen-rods.
JD	..	−0·240	−0·240	
KE	..	−0·338	−0·338	
LF	..	−0·446	−0·446	

Double Truss, with Inclined Tie-rods.—The tie-rod of a roof has hitherto been regarded as occupying a horizontal position, from the extremity of one rafter to that of the other, and a truss of this description answers well enough for spans of limited dimensions, and also in instances where the engineer is not troubled about the question of headway. Frequently this is the very question he has to deal with. To increase the headway, the obvious plan is to raise the tie-rod. But since the strength of any single truss or girder is directly as the depth, the raising of the tie-rod diminishes the depth, and therefore the strength of the truss; or, what amounts to the same, the strain upon the various members of the roof is increased. But this is of comparatively little consequence with other and more important considerations. There are certain given conditions which must be

fulfilled, no matter what the strain may be, and the engineer has only to make the best of them under the circumstances. Supposing therefore that it is necessary to employ a description of truss, with the tie-rod raised above the level of the extremities of the rafters, there are some points of difference existing between the two types which demand notice. A more correct distinction might be made, by calling one the single, and the other the double truss system, as a reference to Fig. 6696 will indicate. The whole roof represented in the diagram consists of two separate trusses A D C, B D C, which are united at the apex C, and held together by the horizontal tie-rod D D. In the diagram, the parts in compression are shown by the thick, and those in tension by the thin lines. The only point of identity that exists between the double and the single trussed roof, is in the king-rod C E, which has no strain whatever on it provided two conditions are fulfilled. These are that the portion of the tie-rod which is connected with it should be horizontal, and not sufficiently long to be liable to sag from its own weight. It might be imagined that, as the horizontal tie-rod D D prevents the feet of the separate rafters from being thrust outwards, it virtually has a strain upon it equal to the horizontal thrust; but such is not the case, and the error must be carefully guarded against. If the tie-rod D D were directly attached to the extremities of each individual rafter, it would then be in the position of that belonging to the single truss system, and the pull upon the portion of it next to the rafter would equal the horizontal thrust of the roof. But in the present instance the pull upon it, due to the thrust of the rafter, can only be transferred to it through the medium of the inclined tie A D, which consequently alters both the direction and amount of the original strain. The strains upon the trusses themselves are dependent both upon the pitch of the rafter and the angles F A D, F B D, of the inclined tie-rods, supposing span and load to be the same. Both these are also dependent upon the absolute pitch of the roof, that is, the angle C A B. There is a particular value for this angle, which causes the strain upon the bar A D to be exactly double that on D C. The advantage of this in practice is obvious, as it simplifies the number of independent parts; since, whatever may be the scantling of D C, it is only necessary to use two bars instead of one to obtain the requisite quantity of material in A D.

6696.



The reduction of the component parts of a structure to as few dissimilar pieces as possible, is a consideration the importance of which cannot be over-estimated.

Before proceeding to analyze by diagram the nature and amount of the strains upon the double-trussed roof represented in Fig. 6696, a few of them may be ascertained by calculation, and will thus serve as a check upon the other method.

Put S for the span, R for the rise or depth of truss from C to E, L for the length of the rafters, W for the total load in tons upon the whole principal, and θ for the angle of the pitch of the roof.

The distribution of the load on the half truss in reference to Fig. 6696 will be $\frac{W}{4}$, at the point F, and $\frac{W}{8}$ at A and C. The total weight at the apex C will be $\frac{W}{4}$, but $\frac{W}{8}$ is all that concerns the strains upon one half of the truss. To find the strain first on the strut F D, put S for the strain, and it becomes $S = \frac{W}{4} \times \cos.\ \theta$. If we take $W = 2$ tons, which makes the load on the half truss equal to unity, and $\theta = 26$ deg., we have $S = 0{\cdot}449$ ton. To determine the strains upon the different parts of the rafter, make the angle $F A D = \theta'$; both these angles θ and θ' can be readily calculated, as the one is a function of the rise and span of the roof, and the other of the length of the rafter and the length of the strut F D, which is known by construction.

Altogether there are three strains brought upon the rafter A C, which affect the portion A F, and two which affect F C. Calling these S_1, S_2, and S_3 respectively, we have their respective values.

$$S_1 = \frac{W}{4} \times \text{tang.}\ \theta;\ S_2 = \frac{W}{4} \times \cos.\ \theta \times \cot.\ \theta';\ \text{and}\ S_3 = \frac{W}{8} \times \frac{\text{sine}\ 90 + (\theta - \theta')}{\text{sine}\ \theta'}.$$

The part of the rafter F C is obviously not directly affected by the weight at F, which produces the strain S_1; therefore the strain upon F C will be equal to

$$(S_2 + S_3) = \frac{W}{4} \times \cos.\ \theta \times \cot.\ \theta' + \frac{W}{8} \times \frac{\text{sine}\ \{ 90 + (\theta - \theta') \}}{\text{sine}\ \theta'},$$

and that upon

$$A\,F = (S_1 + S_2 + S_3) = \frac{W}{4}\ (\text{tang.}\ \theta + \cos.\ \theta \times \cot.\ \theta') + \frac{W}{8} \times \frac{\text{sine}\ \{ 90 + (\theta - \theta') \}}{\text{sine}\ \theta'}.$$

The formula may be put in another form, for let $(S_1 + S_2 + S_3) = M$, then

$$M = \frac{W}{8\ \text{sine}\ \theta'} \times \{ (2\ \text{sine}\ \theta'\ \text{tang.}\ \theta + \cos.\ \theta\ \cot.\ \theta') + \text{sine}\ \{ 90 + (\theta - \theta') \}.$$

Substituting in this equation the correct values for the quantities we obtain

$$M = \frac{1}{4 \times 0{\cdot}258} \times \{ (0{\cdot}516.(0{\cdot}487 + 3{\cdot}349) + 0{\cdot}981) \} = 2{\cdot}86\ \text{tons}.$$

The strain upon F C can be obtained either from the formula given above, or more simply by subtracting from the last. Calling it N, we have $N = (M - S^1), = (2{\cdot}86 - 0{\cdot}243) = 2{\cdot}617$ tons. A comparison should be made between these results and those obtained for the strains upon the rafter, when the tie-rod is horizontal, in order to trace the manner in which the inclination of the ties affects them. The angle θ' becomes an element in the calculation, and assists in complicating it. We may

now ascertain the strains upon the inclined tie-rods, A D and D C. There will be only one upon D C, due to the direct action of the weight at F which will produce equal strains upon A D and D C. These may each be calculated from the formula $S_4 = \frac{S \times \cos. \theta'}{\text{sine } 2\,\theta'} = \frac{S}{2 \text{ sine } \theta'} = 0 \cdot 87$ ton. As this strain is transferred to the apex C, it is multiplied again on the rafter and the tie A D, which also receives an additional strain from the weight directly superimposed at C. Therefore the total strain upon A D is equal to $2\,S_4 + S_5$, but S_5 is equal to $\frac{W}{8} \times \frac{\cos. \theta}{\text{sine } \theta'}$, and may be easily shown to be equal to S_4. For $S_4 = \frac{S \times \cos. \theta'}{\text{sine } 2\,\theta'} = \frac{W}{4} \times \cos. \theta \times \frac{\cos. \theta'}{\text{sine } 2\,\theta'}$. Substituting for the expression sine $2\,\theta'$ its equivalent 2 sine θ' cos. θ', the identity between the two equations is established, and the total strain upon A D becomes equal to 2·61 tons. But there is another strain upon D C due to a part of the strain upon A D. Let the portion of the strain upon A D equal S_6, that affects D C and D E. Then the additional strain upon D C will be given by the formula

$$S_7 = S_6 \times \frac{\text{sine } (\theta - \theta')}{\text{sine } (\theta + \theta')}.$$

Thus making the total strain upon the tie D C equal to 1·37 ton. It only remains now to find the strain upon D E, which is found from the equation

$$S_8 = \frac{S_7 \times \text{sine } 2\,\theta'}{\text{sine } (\theta - \theta')} \text{ or } S_8 = \frac{0 \cdot 50 \times \text{sine } 30^\circ}{\text{sine } 11^\circ} = 1 \cdot 31 \text{ ton}.$$

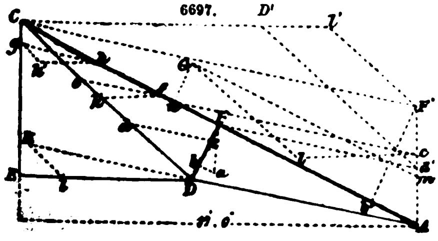
These calculations will be found to check sufficiently closely with those arrived at by the other methods, represented in Fig. 6697, to prove the accuracy of the results for all practical purposes. The strain upon D E is the same as that of the horizontal thrust, modified by the action of the tie-rod A D, for D E might be replaced by an abutment or buttress at the points A and B, without altering the conditions of equilibrium existing in the roof.

TABLE VI.

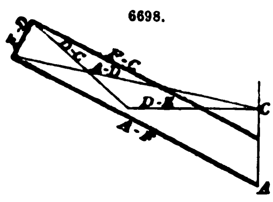
Parts of Truss.	Weight at A.	Weight at F.	Weight at C.	Total Strains.	Remarks.
A F	0	{+0·225 / +1·700}	+0·950	+2·875	Rafter.
F C	0	+1·700	+0·950	+2·650	
F D	0	+0·450	..	+0·450	Strut.
A D	0	−1·750	−0·875	−2·625	Ties.
D C	0	−0·875	−0·500	−1·375	
D E	0	−0·670	−0·670	−1·340	Tie-rod.

The diagram in Fig. 6697 shows the lines necessary to obtain the strains upon the different parts of the truss, and in Table VI. results are given so that they may be compared with those already obtained by calculation. In the diagram there are two methods demonstrated, one showing the actual transference of the separate strains, and the other total strains upon the different members of the truss. According to the distribution of load which is adopted, the total load upon the half principal being 1 ton, the load upon point F is 0·5 ton, and at A and C 0·25 ton respectively. The lines which indicate corresponding strains, are distinguished in the two methods as far as possible by the same letters, with the addition of dotting those belonging to the outside diagram of strains. Any line parallel to any given bar is a measure of the strain, or a part of the strain, upon it. The difference between the two methods is that the one, or successive method, gives the separate strains brought by each weight upon the different parts of the truss, while the other method does not. Take, for instance, the strain upon the two parts of the rafter A F, F C. By the former method the strain upon A F is ascertained by measuring the lines *a b*, *f* C, and *h* C, and that upon F C by *f* C and *h* C. By the latter the strain upon A F is equal to A C + A F, but the strain upon F C is equal to A C + *b'* F, the exact reason for which does not appear, as the manner in which the strains act is not investigated throughout. It is not the result alone that must be considered, but the means by which that result is obtained.

6697.



6698.



It is the preliminary steps which are the most important, and the very points which require accurate elucidation. In Fig. 6698 the same truss is shown with the strains indicated by the lines

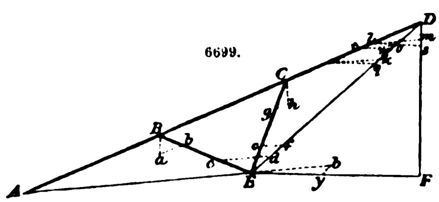
bearing the same letters as in Fig. 6697, and the diagram is drawn in accordance with the method known as the polygon of forces. While the results are perfectly accurate, the method fails, like the other, to trace the action of the strains, and can therefore supply no information, except to those who have already mastered the whole subject. A comparison of these two diagrams will point out that they agree not only in the total, but in the separate strains, much more closely than might be imagined. For example, the total strain upon the tie-rod A D is equal in Fig. 6697 to $c\,d + f\,c + h\,g = 3\,c\,d$.

On referring to Fig. 6698 it will be seen that these separate strains are correspondingly represented by the three subdivisions of the line A D.

Similarly for the strains upon D C, which are equal in Fig. 6697 to $D\,d + K\,l$, and in Fig. 6698 the subdivisions of the line D C. An examination of the method of the polygon of forces will demonstrate that it is in every way superior to the reaction method, as may be termed that shown by the dotted lines outside the truss in Fig. 6697. It is infinitely more elegant, and marks the subdivisions of the strains better. It is, like the other methods, always used in combination with the elevation of the truss, from which the direction of the different bars has to be obtained. Table VI. shows the total and separate strains upon the various parts of the truss. The line A C in Fig. 6698 represents the total reaction at the abutment, and the polygon of forces can thus be readily applied to the actual diagram of the roof. Make $A\,c$, in Fig. 6697, equal 0·75 ton, equal the reaction at A; draw $c\,n$ parallel to A D to meet the rafter; from the point m, in the line $A\,c$, in which $c\,m =$ the weight supported at A = 0·25 ton; draw m G parallel to the rafter to meet n G, drawn parallel to the strut, and complete the diagram.

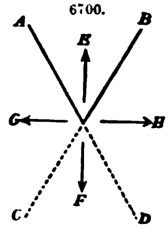
The junction of the various lines in this diagram will point out the manner in which each bar affects the other, although the relation is not so plainly exhibited as by working out the successive strains upon the actual truss itself. If the method of ascertaining the strains be worked out by two different diagrams, it will obviate the necessity for checking their accuracy by trigonometrical calculations, although it will be more satisfactory to check the totals by an altogether independent process, than to employ two, which, although varying in detail, depend upon one and the same principle.

Double Truss, with Two Struts.—When the span of a roof exceeds the limit of about 35 or 40 ft., the simple design already illustrated requires to be somewhat modified. It has been before remarked that the introduction of struts in a braced truss or framework is for the purpose of nullifying the transverse strain, that would otherwise be induced upon the members of the truss. Referring to Fig. 6699, it is clear that when the length of the rafter reaches a certain limit, one strut in the centre, as was shown in Fig. 6697, would not be sufficient to prevent the two halves of the rafter into which it divided it from being affected by transverse strain. Consequently it becomes necessary to use a couple of struts, and divide the whole rafter into three parts. An excellent roof of the form shown in Fig. 6699 may be constructed for spans not exceeding 60 ft. When the dimensions are greater, a different and more complicated description of truss must be used, and for very large spans, the circular or segmental form is the best adapted. In tracing the action of the strains in the diagram in Fig. 6699, the process will be very analogous to that already described for the example in Fig. 6697, making due allowance for the action of the two struts instead of a single one. The distribution of the load will vary, in every instance, according to the number of points at which the rafter is supported, that is, in proportion to the number of struts introduced into the system of trussing.

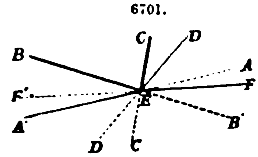


6699.

6700.



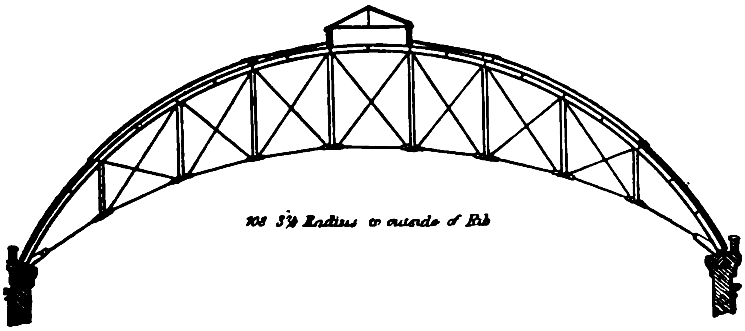
6701.



Distinction between Struts and Ties.—In order to determine which bars are struts and which are ties in any form of truss, when the strain acts upon them in a given direction, let A and B, in Fig. 6700, be two bars meeting at an apex. If the strain act in the direction of the arrow E, they will both be struts, and if in that of arrow F, they will both be ties. Should the force be in the direction of the arrow G, the bar A will be a strut, and B a tie, but if in the direction of H, the bar A will be a tie, and B a strut. The rule may be laid down in words as follows:— If the force or strain acts in any direction within the angle formed by the two bars, they are both struts; but if it acts in the direction of, and within, the angle formed by their prolongation, they are both ties. Again, if the strain acts within the angle formed by the original direction of one of the bars, and of the prolongation of the other, then the bar whose prolongation forms one of the sides of the angle is a tie, and the other a strut. To apply this to the truss in the diagram, let the bars in Fig. 6701 be represented by the same letters as in Fig. 6699, and their prolongations indicated by the dotted lines and corresponding dotted letters. First, let us ascertain how the bars A E and D E are affected by the strain upon the strut B E. Produce B E to B′. The line E B′ represents the direction of the force which lies within the angle A′ E D′, that is, the angle formed by the prolongation of the bars A E and D E. Both these bars are therefore ties. If we now take the bars D E and E F, the direction of the strain lies within the angle F′ E D′, that is, within the angle formed by the direction of one of the bars, and the prolongation of the other, so that

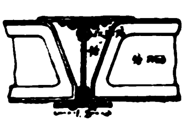
D E is in tension and E F in compression. But as E F is not intended to act as a strut, it undergoes no strain from the direct weight at B, as Table VI. will show.

6702.



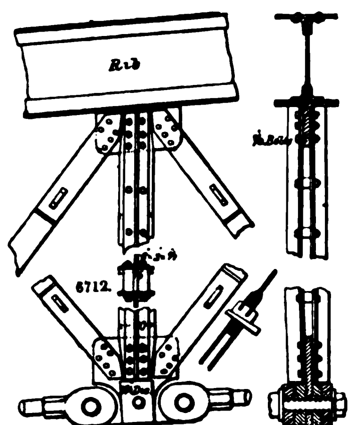
Examples of Roof Trusses.—In Figs. 6702 to 6711 are represented the elevation and details of the City Terminus roof of the South-Eastern Railway, at Cannon Street, London. The span in the clear is 187 ft., the depth of the truss at the centre is about one-sixth of the span. The truss is of the form shown in Fig. 6693, very similar to the one erected at the other terminus of the same railway at Charing Cross. The rib, which has a total depth of 1 ft. 10 in., shown in Figs. 6703, 6704, and 6706, is of the plate type, and consists of an upper and lower flange, composed of one plate and a pair of angle irons each, together with a web ⅜ in. in thickness. A section of the purlin is shown in Fig. 6707, and the manner in which it is connected with the main rib in Fig. 6706. Figs. 6703 to 6705 show the coupling of the struts and ties forming the bracing to the rib and to the tie-rod. Fig. 6712 is a section of the strut, which is in two pieces bolted together, but kept apart by a cast-iron distance piece as in Fig. 6704. The details of the connection of the purlins and of the slating and glazing are represented in Figs. 6708, 6709. The top of the louvre standards and sash-bars, which are of ┳ iron, are shown in Fig. 6710. Fig. 6711 represents the purlin and its attachment to the louvre rail. The outside radius of the main rib is 108 ft. 3¼ in. Figs. 6713 to 6728

6706.

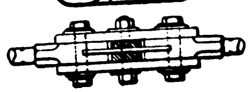


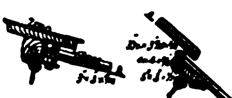
6707.

6703. 6704.



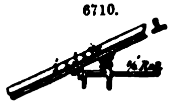
6705.



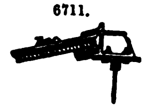


6708. 6709.

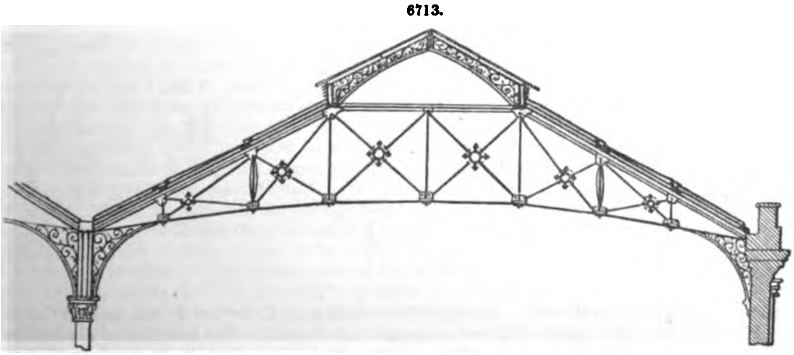
6710.



6711.



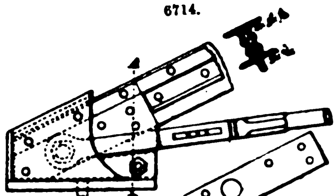
6713.

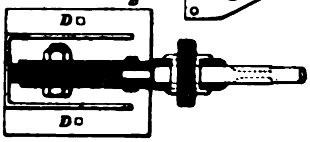


show another example of a truss well adapted for railway station roofs, which is erected over the Broad Street station of the North London Railway. The section of the rib, Fig. 6714, is rather peculiar.

It consists of four angle irons with a web-plate, the lower part of which projects below the lower angle irons. Figs. 6714 to 6717 are the details of the cast-iron shoe, and the method of connecting the

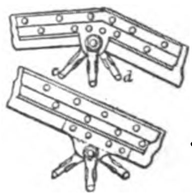
6714.





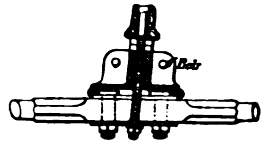
6716.

6718.



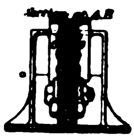
6719.

6720.

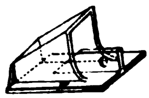


6723.

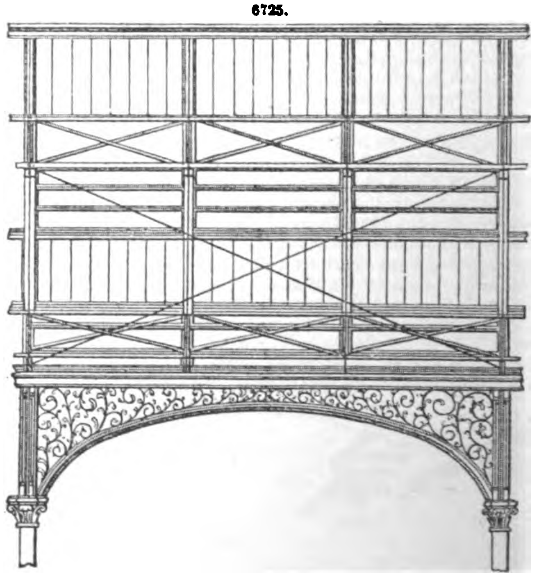
6715.



6717.

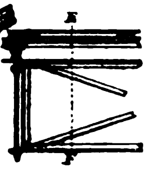


6725.

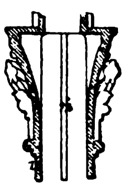


6721.

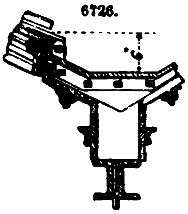
6722.



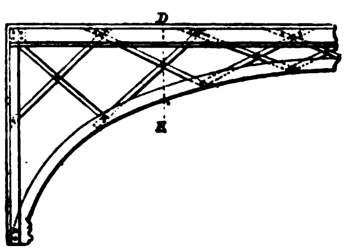
6724.



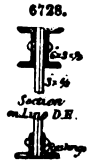
6726.



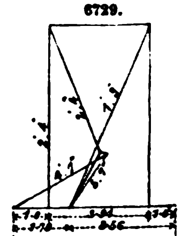
6727.



6728.



6729.



foot of the principal and the tie-rod. Wrought-iron cheeks are bolted on to the ends of the principal rafters, Fig. 6716, in which figure D D are wrought-iron dowels. The junction of the rods with the principal is made as in Figs. 6718 to 6720. A longitudinal elevation of one bay of the roof is given in Fig. 6725, and Figs. 6721, 6722, show the elevation and section of the wrought-iron lattice girder used as the purlins. Fig. 6726 gives the details of the gutter; Figs. 6727, 6728, those

of the curved lattice girder, shown in Fig. 6725. The roof is carried on cast-iron columns, Fig. 6724, and has a very light and elegant appearance.

Wind Pressure.—One diagram will suffice to show the general method of ascertaining the pressure of the wind, and the example selected is a truss of the form in Fig. 6697.

With a nominal pressure on one rafter of 20 lbs. a square foot, the total load will be 5·3 tons, or 2·65 tons on each bay, giving for the loads at the joints of the rafter, considered as continuous, at 1, 1·0 ton; at 2, 3·3 tons; at 4, 1·0 ton. Resolving these parallel forces at 1 and 7, the reaction at 1 is 3·6 tons, and at 7 is 1·7 ton. In Fig. 6729 these quantities have been set off on the line of loads, and the diagram of stress has been drawn.

Books on the subject;—Rondelet (J.), 'L'Art de Batir,' 6 vols. 4to, Paris, 1805–51. Fairbairn (Sir W.), 'Useful Information for Engineers,' Third Series, crown 8vo, 1866. Unwin (W. C.), 'Iron Bridges and Roofs,' 8vo, 1869. Tredgold's 'Carpentry,' by Hurst, crown 8vo, 1871. De Volson Wood 'On the Resistance of Materials,' New York, 1871. Stoney (B. B.), 'The Theory of Strains,' royal 8vo, 1873. Matheson (E.), 'Works in Iron: Bridge and Roof Structures,' royal 8vo, 1873. Cargill (T.), 'Strains upon Bridge Girders and Roof Trusses,' 8vo, 1873. Bow (R. H.), 'Economics of Construction in Relation to Framed Structures,' 8vo, 1873. See also various papers in the 'Minutes of the Proceedings of the Institution of Civil Engineers,' and the 'Transactions of the Society of Engineers.'

ROPE-MAKING MACHINE. Ger., *Maschine zur Verfertigung der Seile;* Ital., *Macchina da corde;* Span., *Maquinaria para hacer cuerdas.*

Ropes are mainly constructed either of the fibres of the hemp plant, or of iron wire. Other vegetable substances and other metal wires are also used; but in the present article only the two important manufactures of hemp rope and iron-wire rope are referred to; and as the treatment of the hemp fibres and the manufacture of them into rope is quite different from the formation of iron-wire rope, the subject naturally divides itself into two branches.

Hemp Rope.—Of the other substances besides hemp which have been found useful and profitable for rope making, the most important are—manilla, the fibres of which are obtained from the bark of a wild species of banana grown in the Philippine Islands, manufactured into a rope commonly known as white rope; jute, grown in Bengal, the fibres of which are used for adulterating hemp; cocoanut fibre, for inferior ropes; Indian hemp, or sunn; and Spanish grass, or esparto. Of these, manilla is the most common substitute for hemp. The machinery employed for manufacturing any one of these several fibres into rope is similar, with slight modifications, to that employed for hemp.

The hemp plant from which the fibre is derived is treated by retting and scutching, in a similar manner to flax, and the hemp thus prepared is packed in bales, each bale of Italian hemp, jute, or manilla, weighing about 2½ cwt.

Chas. P. B. Shelley, in a paper read before the Inst. M. E., 1862, and from which the information in this article is largely derived, states that, in order to form the strongest rope out of a given quantity of material, whether hemp fibres or metallic wire, the fibres should be laid parallel alongside one another and secured at the ends, so that they may take any tensile strain put upon them in the direction of their length; the strength of such a rope will be equal to the strength of each fibre multiplied by the number of fibres in the section. Hemp fibres rarely exceed 4 ft. in length, so that the above method of making a rope exceeding 4 ft. in length will not apply to that material. In order therefore that the fibres may be securely and continuously connected together, they must be placed parallel to one another with the end of one fibre overlapping the end of its neighbour; and to prevent the fibres slipping from one another, friction is produced amongst them by twisting; but as the strength of the fibres is diminished when they are twisted out of the direction of the tensile strain which they are to sustain, no more twist should be given than is necessary to impart sufficient friction to prevent them from slipping and parting endways. It must be remembered that fibres of hemp, like metallic wires, have not the property of felting or uniting into one length by a kind of entanglement or matting together, in the manner common to the fibres of wool and other materials used in spinning. If a bundle of parallel fibres is twisted, those on the outer surface will be stretched and strained considerably more than those near the centre; and the farther they are from the centre the more they will be strained. Hence in constructing cordage it is necessary to form or build it up gradually from small bundles.

When the fibres are laid parallel and in continuous juxtaposition, they are said to form a sliver; and the sliver when twisted is said to be converted into a thread or yarn; and a number of yarns laid parallel and in juxtaposition, bound round by an external serving of yarn to hold them together, forms selvagee, which is the simplest construction of rope. If each of the yarns in the selvagee bore its fair share of strain, this would be the strongest kind of rope; but the objection to its more frequent use is that the outside serving of yarn frets away, and allows water to enter and rot the yarns inside. In order to overcome the objections to selvagee, ropes are made of strands, each strand consisting of a number of yarns twisted together, the strands being again twisted into the rope; the class of rope depends upon the number of strands and their arrangement. The yarn is twisted in the process of manufacture by a motion to the left from the right, or contrary to the motion of the hands of a watch, producing what is termed in rope-making a left-handed twist, being a spiral corresponding to the thread of a right-handed screw. The twist of each strand is in the opposite direction to that of the yarns composing it; and the twist of the rope itself is again in the opposite direction to that of the strands, or in the same direction as that of the yarns.

Ropes are commonly divided into three classes, known as hawser-laid, shroud-laid, and cable-laid ropes. Hawser-laid ropes are composed of three strands twisted together; the number of yarns for each strand in different sizes of hawser-laid ropes is dependent on the diameter or number of thread of the yarn. Shroud-laid ropes are composed of four strands. Cable-laid ropes are composed of three hawser-laid ropes twisted together. Cablets are small cable-laid ropes measuring from 1 to 10 in. in girth; larger sizes are termed cables. Shroud and hawser laid ropes seldom

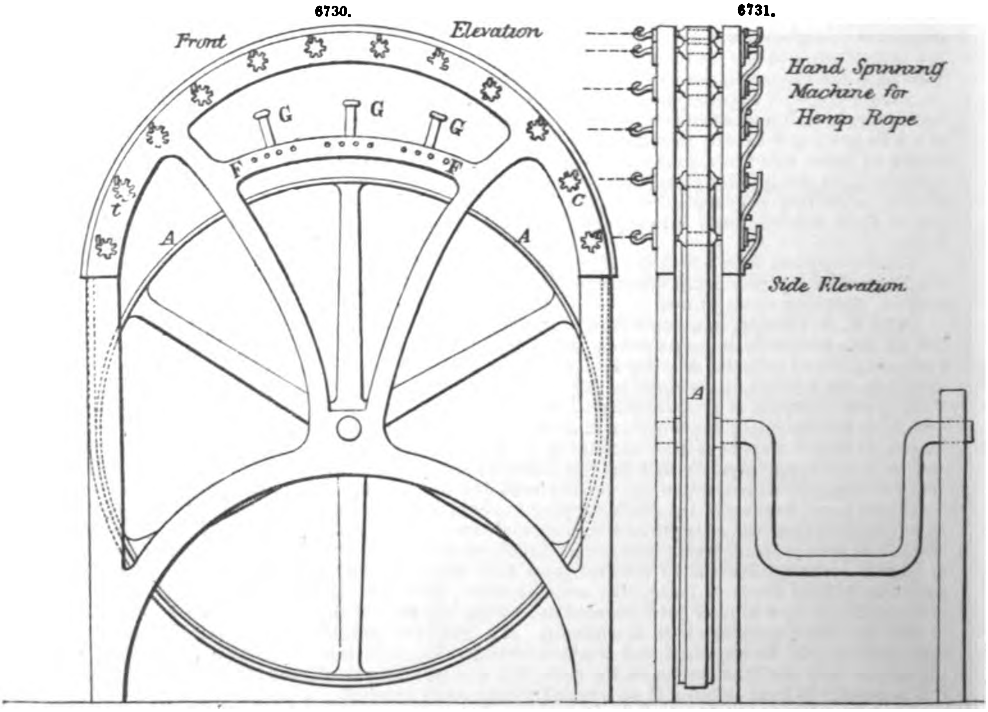
exceed 10 in. in girth. A core or heart is used in shroud-laid ropes; it is made of rope, and is placed in the centre of the strands, running from end to end of the rope with the strands laid round it. In old worn-out ropes the core is always found to be broken in consequence of the stretching of the strands; for the strands being twisted spirally, and the core straight, the strands will give more under a load than the core, which cannot therefore be relied upon for adding strength to the rope; but it assists materially in keeping the strands in position during the manufacture of the rope by hand. Flat hempen ropes are made of four or six ropes, each composed of three strands, and laid alternately to the right and to the left; these are stretched side by side and sewn through in a zigzag direction.

Before the hemp is spun into yarn it has to be freed from dust and hard knots, and the fibres combed, so that they may be separate and parallel to one another. This process is called heckling, and is done either by machinery or by manual labour; the machinery for the purpose is similar to that used in the preparation of flax.

The next process which the fibres undergo is that of spinning into yarns. Hand-spinning is done on a long strip of ground called the rope-walk, which is generally covered by a low roof; sometimes the shed has an upper floor with a low roof, and then the spinning is done on the upper floor, and the other parts of the manufacture on the ground. The length of the walk and shed is about 1230 ft., or a little over 200 fathoms, and the width about 30 ft. The tie-beams of the roof are placed every 30 ft. or 5 fathoms apart, and carry a row of hooks on the under side.

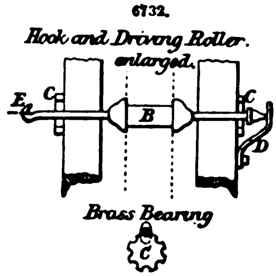
The hand-spinning machine, Figs. 6730, 6731, is formed of two cast-iron frames with a band-

6730. 6731.



wheel A between them, driven either by a man at the winch-handle at the back, or by steam power. A band passing round the wheel passes over twelve wood rollers or whirls B, 1½ in. diameter, as shown enlarged in Fig. 6732, fixed on steel spindles about ⅜ in. diameter, which revolve in notches or bearings in the brass discs C screwed in the frames of the machine; the spindles are kept in their bearings by a ribbon of wrought iron screwed upon the outside of the frame. On the back end of the spindle is a shoulder, and between this and the brass disc is a loose collar to take the pull of the yarns in spinning; the spindle is kept in by a finger D fixed on the back of the frame. The front end of the spindle is drawn out into a hook E. The notches in the brasses C, shown enlarged in Fig. 6733, are for the purpose of forming fresh bearings for the spindles; there are eight notches in each brass, and when one notch is worn down the brass is turned to bring another notch round; when the whole of the notches are worn down a new brass is put in. The twelve hooks and whirls are set upon the semicircular upper part of the machine, and are made to revolve by the band which passes over them from the driving wheel A.

6732.



6733.

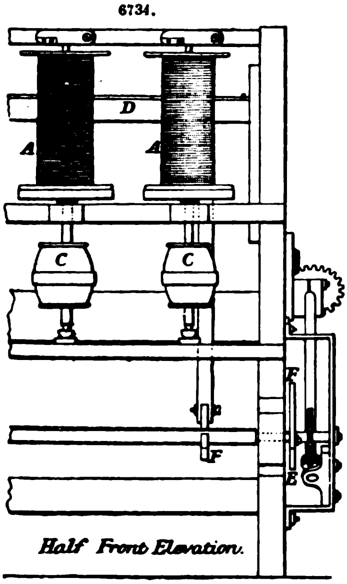
Each spinner before beginning to spin takes up a bundle of hemp sufficient in quantity to spin

one thread of yarn of the required length; he places the bight or middle of the length of the fibres in front of him, and turns the ends round his waist, crossing them behind. If the shorts are to be worked into the yarn they are tucked below the bight. Each spinner carries in his right hand a piece of stout list. There are twelve spinners to each machine, one to each hook. The spinner draws from the bight or front of the bundle round his waist a sufficient quantity of fibres for the size of the yarn or thread about to be spun, thus forming a sliver, which he twists with his fingers, and hooks the bight of the sliver on to one of the revolving hooks of the machine. He then walks backwards towards the bottom of the rope-walk, drawing the hemp from his waist and forming a sliver with his left hand, pulling some of the fibres back if they come forward too quickly, and drawing some forward if there are not enough to keep up the required size of yarn. The sliver passes through his right hand, with which by means of the piece of list he firmly grips it, so as to form the yarn. The spinner thus prepares the sliver and forms the yarn, while the machine gives it the twist. Care must be taken not to place the ends of one set of fibres too near to the ends of the next set, not giving them sufficient lap, otherwise the yarn will part by the fibres slipping endways from one another; and also to keep the fibres even and regular in thickness, in order that the yarn may be of equal strength throughout. The spinner's pace in walking backwards must be uniform and in accordance with the speed of the revolving whirls. The speed of the whirls and the amount of twist of the yarn is dependent upon the quality of the rope to be manufactured.

The twelve spinners are divided into three sets of four each; four risers, four middlemen, and four leaders. The four risers work from the four hooks on the left side of the machine, the four middlemen from the four middle hooks, and the four leaders from the four hooks on the right of the machine. All the twelve spinners start at once from the machine in the morning. The four risers spin down the walk a yarn one-third of 160 fathoms long and then stop, while the middlemen and leaders continue to spin past them. The four yarns of the risers are now unhooked from the whirls by a man at the top of the walk, and are passed each through a hole F in the frame of the spinning machine, Fig. 6730, to a reel at the back, upon which they are wound; the men at the bottom end of the yarn still hold on so as to prevent the yarns from untwisting, and follow it up to the machine as it is wound on to the reel. They then twist the ends of these yarns on to one of the holding pins G on the cross-bar of the machine frame, and start spinning again with four fresh yarns, which they will this time spin down to the whole length of 160 fathoms before stopping. The four middlemen spin down the walk a yarn two-thirds of 160 fathoms long and then stop, while the leaders still go on and pass them. Their four yarns are taken off the hooks of the machine and spliced on to the ends of the four yarns which were left on the holding pin by the risers; the yarns of the four middlemen are then wound on to the reel, the men following them up the walk and fastening the ends on to one of the holding pins; the middlemen then start fresh yarns of 160 fathoms length and spin down the walk. The four leaders spin down the walk a yarn 160 fathoms long, and then they also stop, and their four yarns are taken off the hooks and spliced on to the ends of the four yarns left on the holding pin by the middlemen; the yarns of the leaders are then wound up on the reel, followed up by the men.

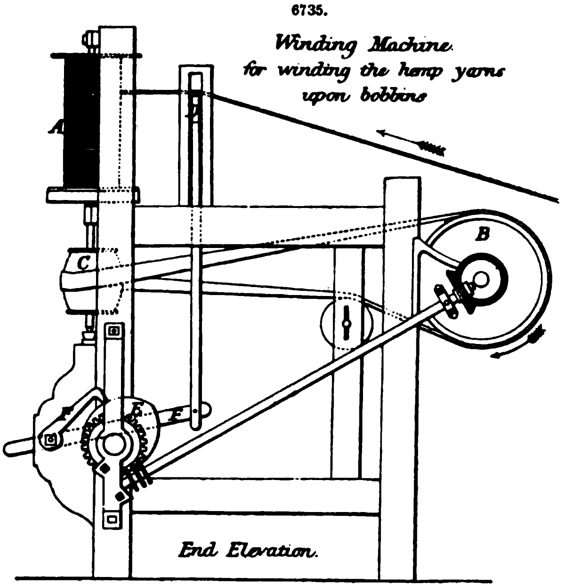
As the spinner proceeds down the walk he tosses the yarn with his left hand on to one of the hooks in the rafters in order to support it; and in coming back he jerks it off again. The distances of one-third, two-thirds, and 160 fathoms are chalked on the side of the shed, and as the spinners of each set come to the distance they shake their yarns, and thus signal to the man at the machine for the yarns to be unhooked and reeled up.

6734.



Half Front Elevation.

6735.



End Elevation.

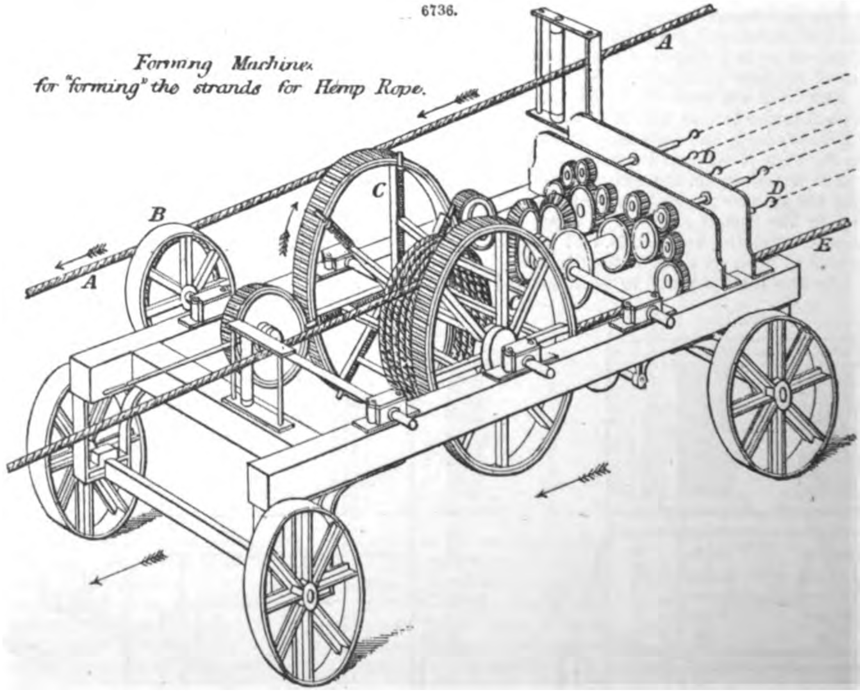
When the reel behind the spinning machine has been filled with the four lengths of yarns spun, it is taken to the winding machine, Figs. 6734, 6735, which separates the four yarns on to

four separate bobbins A, A, and also reverses the lay of the yarn end for end, so that the fibres may lie in the proper direction for passing through the next process. Fig. 6734 is a front elevation of half the length of the machine, showing two of the four winding bobbins A, A; and Fig. 6735 an end elevation. The bobbins are driven from the drum B, which extends the whole length of the machine, by means of straps passing round the four riggers C, C, fixed on the vertical spindles that carry the bobbins A. The full reel containing the four yarns from the spinning machine is mounted on a temporary frame behind the winding machine, and the ends of the four yarns are led to the bobbins over a sliding bar D, which has a vertical reciprocating motion given to it by the cam E and levers F, for the purpose of filling the bobbins regularly and equally from end to end. Other forms of winding machines are used, but the principle of construction is the same in all. When the four bobbins are filled they are replaced by empty ones, until the whole of the reel from the spinning machine is wound off upon bobbins. The four full bobbins are then taken away and placed vertically in a large wooden frame called the bobbin-frame, which holds from 150 to 200 bobbins. Each bobbin contains about 14 lbs. of yarn.

The next process is that of twisting a number of yarns together into a strand, which is termed forming, and is effected in the forming machine and in the shed covering the rope-walk. Having ascertained the number or size of the thread that is of sufficient thickness to form the required strand, the number of yarns corresponding to that size of thread is selected; and the ends of the yarns of this size are drawn from the bobbins and brought in a converging direction to a square iron plate, called the register plate, perforated with a number of round holes. Each yarn is made to pass through a separate hole in the register plate, and the yarns all converge thence into one common point through the forming board, in which is a taper steel tube with a trumpet-mouthed taper hole through it. The hole in the tube varies in diameter for each size of strand and is selected by a gauge; the diameter of the tube for one of the strands for a rope of 3 in. girth is $\frac{8}{16}$ in. at the small end and $\frac{9}{16}$ in. at the large end, and for the strands of a rope of 2 in. girth it is $\frac{5}{16}$ in. at the small end and $\frac{7}{16}$ in. at the large. The convergent yarns are entered into the tube at the large trumpet-mouthed end, and are forced through, fitting tightly into the tube; they are thus squeezed together previously to being attached to the forming machine.

The forming machine for twisting the hemp yarns into strands, Fig. 6736, is mounted on

6736.

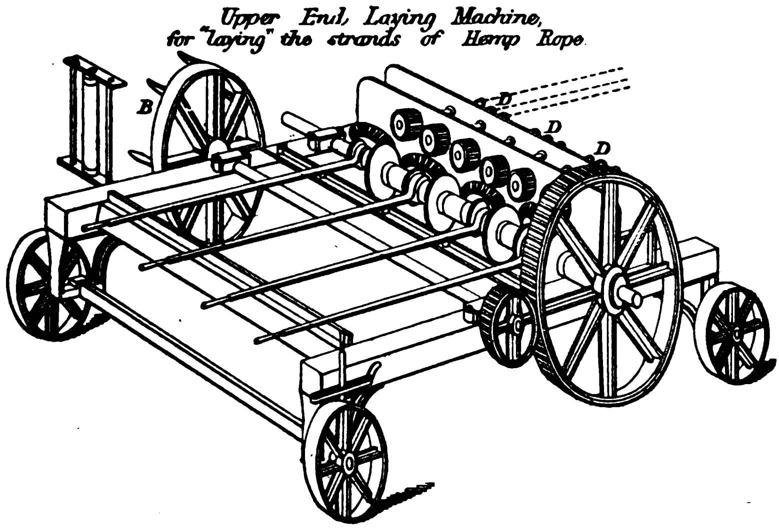


wheels, and made to travel along the length of the rope-walk by the endless rope A, called the fly-rope, which passes round pulleys at the top and bottom of the walk and acts as a driving rope, being driven by an engine. This fly-rope takes a turn round the whelp-wheel B, which gives motion by gearing to the drum C and the twisting hooks or nibs D for forming the strands. A fixed rope E, called the ground-rope, made fast at the ends of the walk, is coiled round the drum C, so that by the revolution of the drum the machine is made to travel along the walk. During the travel of the machine the yarns hooked upon each nib are drawn out and twisted together into a strand; each nib taking the number of yarns required to form the strand. The speed of revolution of the hooks is regulated according to the kind of rope into which the strands are to be made; and the great object is to adjust the rate of travel of the machine in

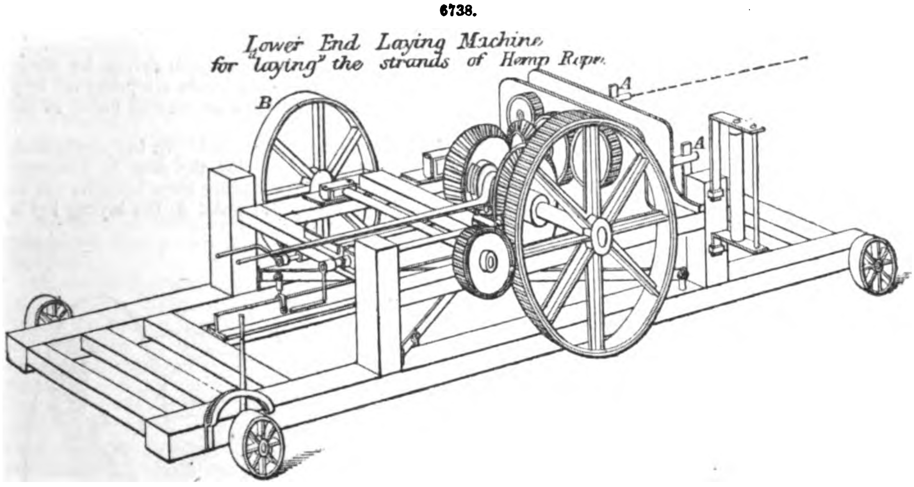
relation to the speed of the hooks, so that the strands may receive the proper amount of twist in a given length. For this purpose the staves of the drum C which gives the travel of the machine are made capable of being shifted to or from the centre of the drum by means of adjusting screws, so as to diminish or increase the rate of travel.

After leaving the forming machine the strands are laid into a rope by two laying machines, Figs. 6737, 6738, one at the upper end of the walk and the other at the lower end. In this process, instead of being twisted together as the yarns are in the previous process, the strands are

6737.



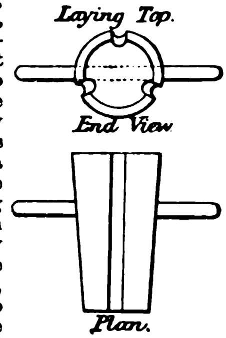
6738.



placed or laid in their spiral position in the rope without being twisted. The laying machine at the upper end of the walk, Fig. 6737, is fixed, and the three strands to form the rope are attached to the hooks D, which are made to revolve in a similar manner to those in the previous forming machine, by the fly-rope passing round the wheel B. The lower end laying machine, Fig. 6738, is left free to travel part way up the walk as the length of the strands become shortened by their being laid into a spiral in the rope. The wheel B here drives the two forelocks A, A, to one or other of which the strands are made fast, according as the twist of the rope is to be right-handed or left-handed. The three strands for the rope are stretched tight along the length of the walk from the hooks D of the laying machine at the upper end to the forelock A of the lower laying machine, and are supported off the ground and kept separated by means of posts, called samson posts, placed at every 5 fathoms length, with pegs to carry the strands. A taper piece of wood with three grooves, called the laying top, shown enlarged in Figs. 6739, 6740, is then inserted between the strands close to the lower machine, with its smaller end towards the forelock A, one of the strands lying in each of the grooves. A transverse hole is made through the laying top, through which is passed the top stick or handle that the top is held by. The laying

tops are made of various sizes, according to the size of rope required; for a rope of 3 in. girth the top is 12 in. long, 10 in. diameter at the larger end, and 8 in. at the smaller. When the rope is more than 3½ in. in girth, a top cart is used for supporting the top.

6739.



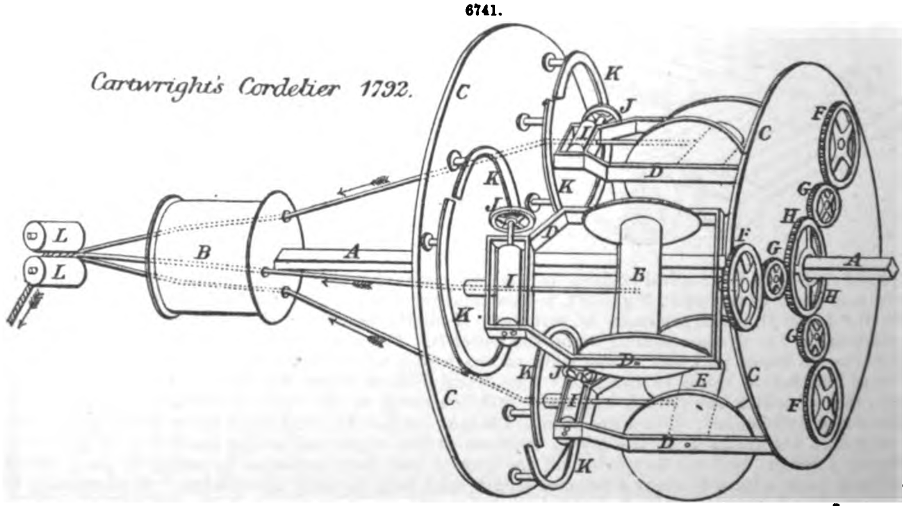
6740.

The laying machines being now put in motion, the revolution of the forelock A, Fig. 6738, gives the twist or hard of the rope, while the laying top is firmly held by the handle from turning. The hooks D, Fig. 6737, at the other ends of the strands are made to revolve in the opposite direction to the forelock A, which is twisting the rope, so that the twist put into each of the individual strands at the point where they are united into the rope immediately behind the laying top is taken out again by the hooks at the upper end. The laying top is gradually pressed forwards by the closing of the strands upon one another behind it; its motion requires to be very regular, and it is prevented from moving forwards too fast by a tail or piece of rope attached to the top handle, which is coiled round the rope already twisted, and thus acts as a drag to the top. The two laying machines must be driven at exactly the proper speed relatively to each other, so that the twist put into the separate strands at the laying top may be exactly neutralized by the revolution of the hooks; otherwise if the hooks revolve too slow, they will partially untwist the individual strands, since the twist of the yarns in each strand is in the contrary direction to that of the strands in the rope; or if too fast, the strands will become twisted tighter. In order that the man holding the laying top may find out how the machines are working, whether too fast or too slow relatively to each other, he makes a mark on one of the strands close to one of the supporting posts; if the strands are being twisted too fast by the hooks of the upper laying machine, the mark on the strand advances towards the upper end of the walk, from the yarns themselves becoming twisted tighter together in each strand, and the length of the strand is shortened; but if too slow, the mark recedes towards the lower end, from the partial untwisting and consequent lengthening of the individual strands. In laying the strands care is required with regard to the angle that the strands take. Should the tension on the strands become unequal, the required additional twist is given to those which have got slack by throwing out of gear those hooks of the upper laying machine to which the tighter strands are attached, and allowing the others to continue revolving until all the strands have again become equally strained. As the formation of the rope proceeds, the lower laying machine is gradually drawn up the walk by the shortening of the strands as they are laid together into the rope; and press weights are placed on the frame of the machine to retard its motion and hold the rope tight enough during the laying. Formed strands of 180 fathoms length will make 120 fathoms of hawser-laid rope; the length of the strands will be determined by the length of rope required.

After the rope is taken off the laying machines, it is coiled on to a drum driven by steam power, being guided from end to end of the drum by the workman, whose hands are protected by a piece of old cordage twisted on the rope that is being coiled; this gives a polish and finish to the surface of the rope.

The previous description has referred only to ropes manufactured by hand. In the application of machinery to this manufacture, Cartwright appears to have invented the first rope-making machine, which is the basis of others since constructed, his Cordelier having been brought out in 1792. Fig. 6741 shows the cordelier, which revolves on the horizontal shaft A, the laying top B

6741.

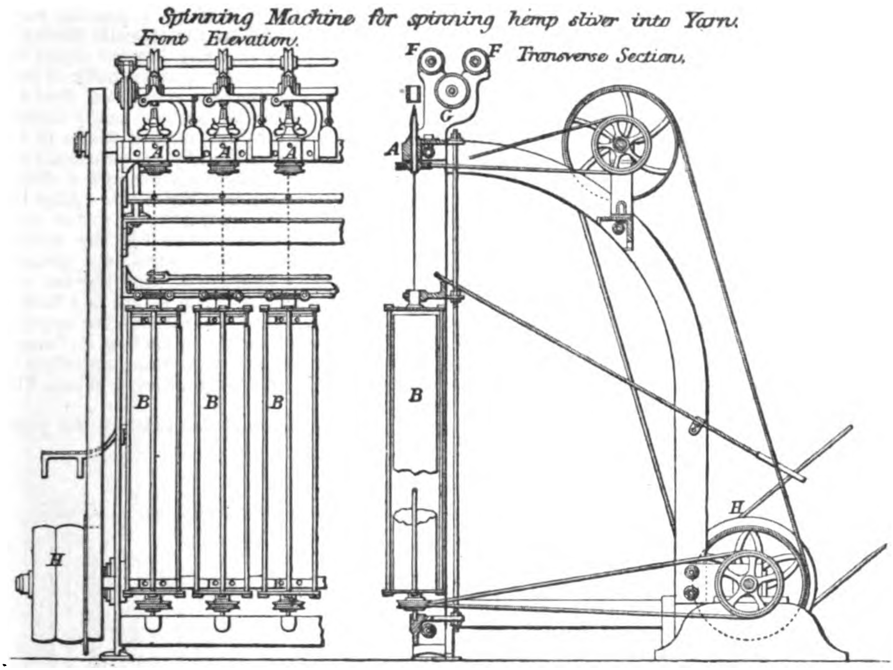


serving as the bearing at one end of the shaft, having holes through it for the strands to pass through. In the discs C, C, fixed on the shaft A are centred the three horizontal spool-frames D, carrying the spools E, which contain the three strands to be laid together. As the cordelier

revolves, the axes of the spools are preserved constantly parallel to themselves by the spool-frames D being made to rotate on their bearings once for every revolution of the machine, by means of the pinions F on the spool-frame bearings, and the counter-wheels G gearing into the central dead-wheel H, which is of the same diameter as the pinions F, and is held stationary while the shaft A

6742. 6743.

Spinning Machine for spinning hemp sliver into Yarn.

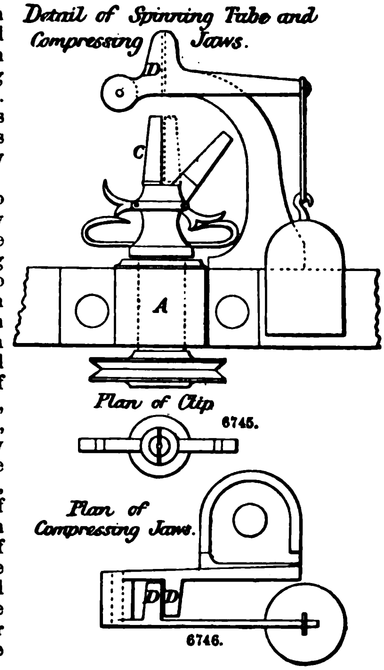


revolves within it. The bearings at the other end of the spool-frames D are hollow, for the strands to pass through to the laying top B. The strand is drawn off the spool by the pair of delivering rollers I, which receive motion by a worm-wheel J on the axis of one of them gearing into the worm K within which the spool-frame revolves. The drawing rollers L, L, draw the finished rope forwards as fast as it is made, and hold it from turning. This machinery was a few years afterwards improved by Huddart.

Huddart's spinning machine for converting sliver into yarn is shown in Figs. 6742, 6743. The sliver, previously formed by another machine, is contained in the twelve cans B, which are driven rather faster than the spinning tubes A, in order to give a slight preparatory twist to the sliver. The spinning tube A, shown enlarged in Figs. 6744, 6745, has a spring clip C at the top, which grips the thread spun from the sliver and twists it with great rapidity, thus effecting the spinning. The thread so formed is then subjected to a considerable amount of tension by being drawn through the compressing jaws D, Figs. 6744, 6746, and round the stretching pulleys E, F, and G, Fig. 6743, the last of which is a double pulley with two grooves. The thread passes first over the pulley E, then under one of the grooves in the pulley G, over the pulley F, and again over the second groove of the pulley G, whence it passes away to a winding drum at the back of the machine. The main driving shaft of the machine is driven from the engine by a belt over the fast-and-loose pulleys H. There are three horizontal winding drums behind the machine, upon which the yarns are wound, each drum taking the yarns from four of the spinning tubes; the yarns are delivered upon the drums through holes in a longitudinal traversing bar, which is moved endways backwards and forwards by a rack and pinion so as to guide the yarns from end to end of the drums alternately.

6744.

Detail of Spinning Tube and Compressing Jaws.



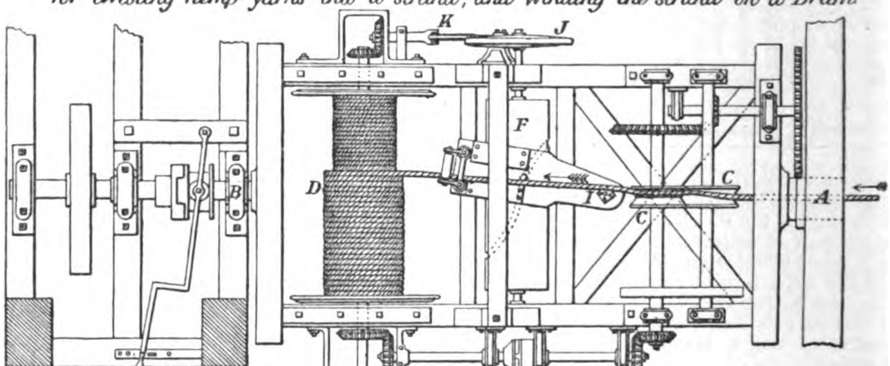
If the ropes are to be tarred, the tar is applied to the yarns on leaving the spinning machine. For this purpose they are first wound off from the drum behind the spinning machine upon a winder called a whimwam, made of a light open frame of iron and wood revolving on a horizontal shaft. The loose ends of the four yarns on the drum are attached to a hook at the right end of the winder, which is then turned by a winch-handle to wind the yarns on, the yarns being guided on from end to end by a traversing plate with four holes in it which receives the required traverse motion from the shaft of the winder. On reaching the left end of the winder the yarns are doubled round the hook at that end, and the winch is then turned in the opposite direction, winding the yarns on till they reach the right end, where they are similarly doubled round the hook at that end, and the winding is then again reversed. When a sufficient quantity of yarn has been put on the winder, the hook at one end is taken out and the yarn is uncoiled from the winder, thus forming a long skein called a haul, which is then coiled upon a small circular turn-table, about 4 ft. diameter, mounted on wheels. The haul of yarns is then taken to the tarring shed, and uncoiled from the turn-table into a caldron of tar heated by fire or steam; one end of the haul is lifted from the tar, and by means of a capstan is drawn through a sliding nipper or squeezer for the purpose of squeezing out the superfluous tar from the yarns. After the haul has lain for some time, the longer the better, the four yarns are separated and wound on to four bobbins by the winding machine previously described; and are then passed to the bobbin-frame ready for being twisted into strands. Huddart did not make the yarns into a haul previous to tarring, but passed them from bobbins direct from the spinning machine through the tar, and thence through nippers to the register plate of his registering machine. The length of a haul is 55 fathoms; it contains about 144 threads, and takes about 20 minutes to pass through the squeezer from the tar caldron, that is about 16 ft. in a minute. The tar used should be the best Archangel tar, of a good bright colour, and heated to a temperature of 212° Fahr. The usual proportion of tar remaining in the yarns is from one-quarter to one-fifth of the weight of the untarred yarns. The yarns when tarred ought to be of a bright brown colour.

The registering machine, shown in plan in Fig. 6747, is for the purpose of twisting the yarns

6747.

Plan of Registering Machine

for twisting hemp yarns into a strand, and winding the strand on a Drum



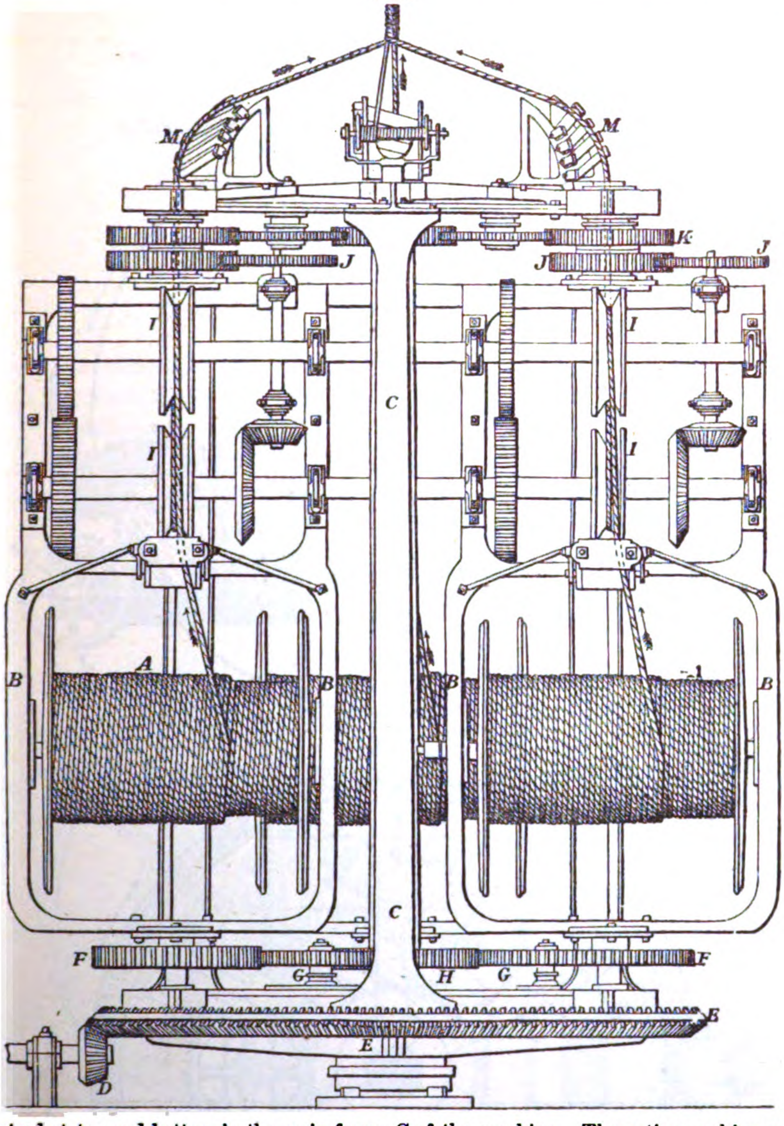
into a strand and winding the strand upon a drum as fast as it is formed. The whole machine revolves with rapidity on the horizontal bearings A, B, being connected with the driving power by a sliding friction-clutch at B. The strand enters through the hollow bearing A, which grips it tight and thus twists the yarns into the strand by its revolution. The strand is drawn in by the pair of drawing pulleys C, taking half a turn round each, and is delivered upon the winding drum D by the guiding frame E, which is made to move from end to end of the drum by means of a stud on the frame working in a spiral groove cut in the barrel F. The drawing pulleys C, winding drum D, and grooved barrel F are all driven from the spur-wheel G gearing into a stationary pinion fixed to the plummer-block in which the bearing A revolves. As each successive coil of strand wound on the drum D increases its diameter, an increased tension would be thrown on the strand, a friction-clutch is therefore inserted at H in the intermediate shaft which communicates the driving motion from the drawing pulleys C to the winding drum D, in order to prevent the drum from overwinding the pulleys, the friction being adjusted to the exact limit of tension desired in the strand. The guiding frame E, which delivers the strand from end to end of the winding drum, vibrates on a centre at I, and its rate of travel is varied for different sizes of strand by changing the worm-wheel J on the spindle of the grooved barrel F; the universal joint K allows of the driving worm being set at different inclinations for gearing into a larger or smaller worm-wheel J.

The strand made by the registering machine is wound off the drum D on to a loose reel, so that when transferred to the drum of the spool-frame in the laying machine it may lie the same way end for end as on the drum D, in which state it is ready for being laid into a rope. The length of the strand is measured by passing it over a pulley of definite diameter, to which is attached a counter with a dial, indicating the number of fathoms of strand that have passed over the pulley.

Fig. 6748 is a general elevation; Fig. 6749 a plan at the top; and Fig. 6750 a sectional plan through the spool-frames; Fig. 6751 is a side elevation of one of the spool-frames to a larger scale

of the rope-laying machine for laying the hemp strands into rope. The three spools A, filled with strand from the registering machine last described, are carried in the vertical spool-frames B, which

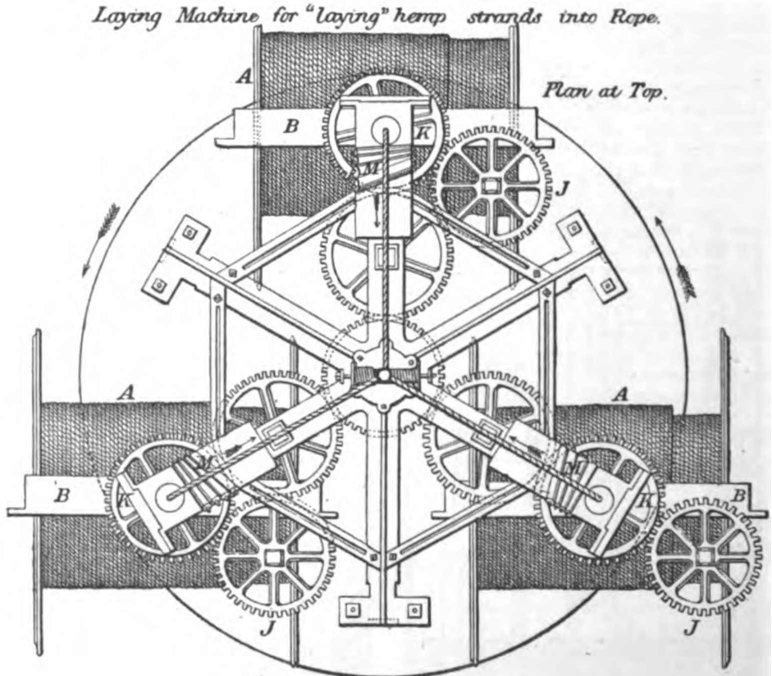
6748.

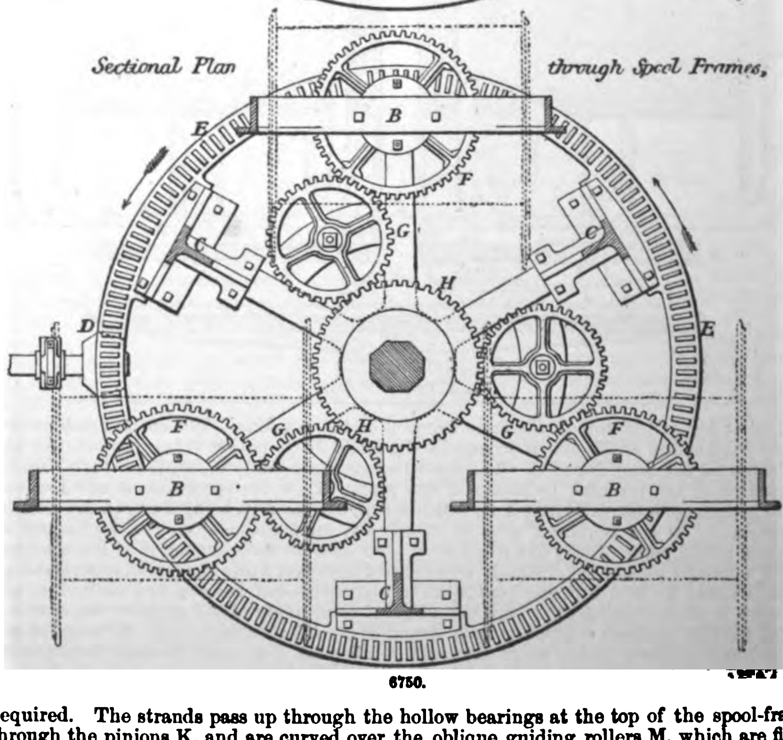


are centred at top and bottom in the main frame C of the machine. The entire machine revolves round the fixed centre shaft, and is driven by the small bevel-pinion D gearing into the wheel E at the bottom of the main frame C. The spool-frames B are made to rotate on their axes during the revolution of the machine by means of the pinions F on the spool-frames and the counter-wheels G gearing into the dead-wheel H, which remains stationary, being fixed on the centre shaft of the machine. If the pinions F were of exactly the same diameter as the dead-wheel H, the spool-frames would make exactly one rotation on their axes for each revolution of the machine, and the spools would be preserved constantly parallel to themselves while the machine revolved, so that the strands would be laid into the rope without any additional twist in the individual strands. But in order to ensure the yarns in each strand being thoroughly closed upon one another, a slight additional twist or forehard is given to each strand in the act of laying it into the rope, by making the spool-frames perform rather more than one rotation on their axes for each revolution of the machine, since the twist of the yarns in each strand is in the contrary direction to the twist of the strands in the rope. The pinions F on the spool-frames are therefore made of smaller diameter than the dead-wheel H in the proportion of 13 to 14. From the spools A the strands are drawn off round the stretching pulleys I, I, as dotted in Fig. 6751, which are driven by bevel-gearing and pinions J from a dead-wheel fixed on the centre shaft at the top of the machine, with counter-

wheels and pinions K similar to those at the bottom. The strand is pressed tight into the groove of the upper stretching pulley I by the small tightening pulley L, Figs. 6751, 6752. The spool A is retarded from unwinding too fast by a friction-brake, which is adjusted to any degree of tight-

6749.



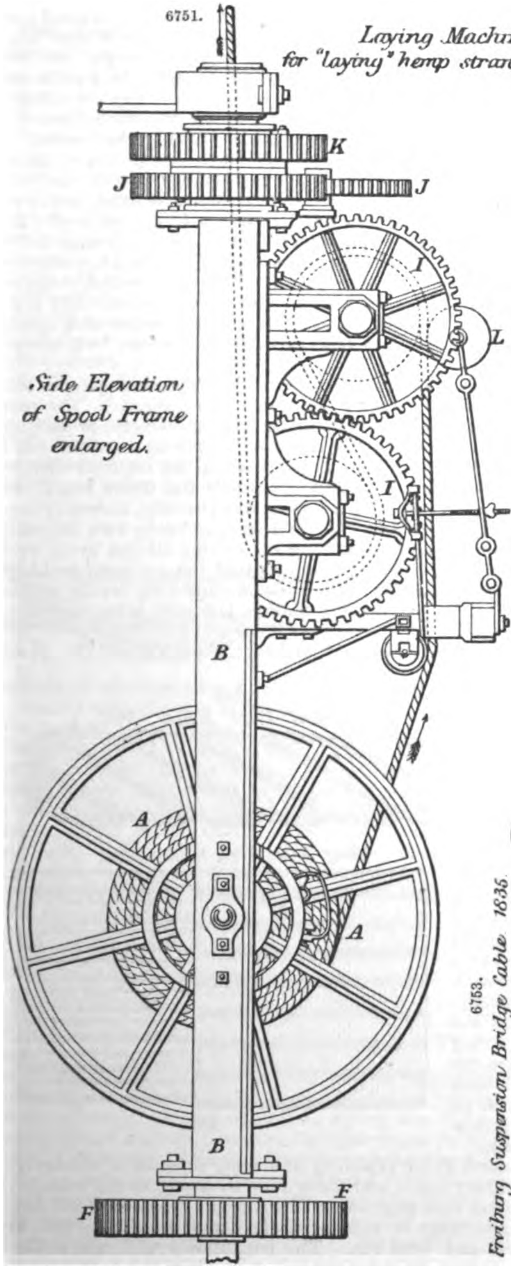


6750.

ness required. The strands pass up through the hollow bearings at the top of the spool-frames B and through the pinions K, and are curved over the oblique guiding rollers M, which are fixed at varying inclinations in order to prevent the strands from slipping off. The three strands then

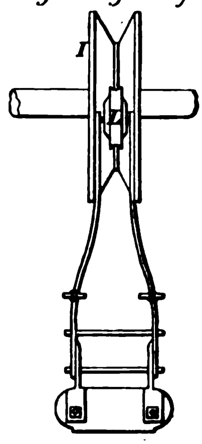
unite at the centre, and are laid together into the rope by the revolution of the machine, each strand being laid into the rope with the required amount of forehard by the simultaneous rotation

6751.

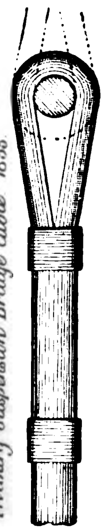


6752.

Tightening Pulley

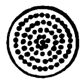


6753.

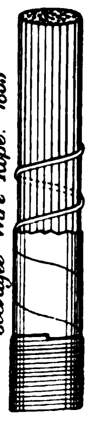


Freiburg Suspension Bridge Cable 1835.

6755.



6754.



"Selvagee" Wire Rope. 1835

of its own spool-frame in the contrary direction to the machine. The newly-made rope is carried upwards to another machine, where it is stretched over and under three pulleys driven by steam power; and as it passes from the last pulley it is compressed by a roller kept against the rope by a strong steel spring. It is afterwards finally coiled away in a warehouse.

Wire Ropes.—Wire ropes were used as early as 1822 for the supporting cables of a suspension bridge at Geneva, and also for the Freiburg Suspension Bridge of 807 ft. clear span, erected in 1835. The wire ropes in the latter case, Fig. 6753, are constructed of twenty bundles or strands of straight iron wire 0·125 in. diameter, stretched parallel, forming a rope 5½ in. diameter, and bound round with wire at 2-ft. intervals.

The first form of wire rope regularly manufactured was known as selvagee, Figs. 6754, 6755. It

consisted of a number of hard or unannealed wires, of about 12 to 16 wire-gauge, or 0·110 to 0·065 in. diameter, which were stretched parallel and bound together by a fine wire of about 20 wire-gauge, or 0·036 in. diameter, wound spirally around; after which a parcelling of woollen list was also wound round in the contrary direction, with the edges lapped so as to cover the wires entirely; the rope was completed by a service of tarred yarn wound on in the contrary direction to the list. The method of making the rope was simply to warp or stretch the wires at a uniform tension over two hooks set at the distance of the length of rope required to be made, passing the wires backwards and forwards over the hooks as many times as was necessary to make up the size required. A solution of india-rubber boiled down in linseed oil, with a mixture of resin and tar, was rubbed carefully into the body of the rope previous to binding up, and after the binding wire had been wound on, the solution was again applied to the exterior wires to prevent oxidation, the process of galvanizing not being practised at that time. The parcelling of list was also saturated with the solution, the yarn being tarred as usual. The binding and parcelling were always done by hand, before the rope was taken off the hooks; but the service of yarn was usually laid on by a machine for that purpose, though occasionally also by hand. The method of attaching the fittings, such as shackles, thimbles, and dead-eyes, was either by forming an eye during the process of warping to receive them, or by inserting the end of the rope stripped to the wires into a conical socket attached to the shackle, and turning back the ends of the wires so as to prevent the rope being drawn out. But more generally the fittings were turned in. that is, the end of the rope was doubled round and seized or bound to the standing part. It will be seen that it was very difficult to splice this form of rope, owing to the absence of twist or lay.

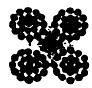
Ropes thus made were exceedingly rigid and non-elastic, but possessed greater strength than any other construction; in fact, the entire strength of the wire was preserved. The parcelling and service added to the size, but not at all to the strength, being intended only for protecting the wires.

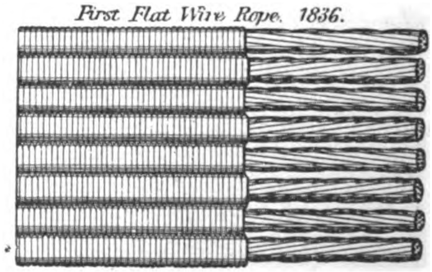
The machinery for making these selvagee ropes consisted simply of the two hooks over which the wire was warped, which were attached to movable posts set at the required distance asunder. The serving machine was a long wood trough, extending nearly the entire length of the rope-ground, having a revolving shaft at each end, with a hook at its extremity, and carrying a fast-and-loose pulley, over which a driving band passed. The two serving hooks were driven at the same speed of about 400 revolutions a minute; and the shifting forks of the driving bands were connected by a cord extending throughout the length of the ground, so that the workman could stop or start the machine at any part. An ordinary serving mallet was employed for laying on the yarn, and was guided by the workman, who also regulated the tension, the yarn being supplied from reels hung overhead.

The next description of wire rope was known as formed rope, Figs. 6756, 6757. It consisted of a number of soft or annealed wires, usually about 14 wire-gauge, or 0·085 in. diameter, formed or twisted into a strand, but with little or no regard to regularity; and four of these strands were laid into a rope, though this number was not always the same. The number of wires was varied according to the size of rope required, and occasionally the size of wire was altered to suit circumstances. These ropes closely resembled ordinary hemp ropes in appearance. The twist caused by forming the strands remained in the wire as a permanent set, and the strands were laid together with an extra amount of twist or forehard in each strand, which was necessary to keep the rope together. Little or no injury was done to the wire by this process, owing to its being annealed, and also from the length of the twist of the wires in each strand, which was usually about 12 in. pitch; but it would be almost impossible to use hard wire in this manner.

6756.

6757.





6758.

6759.

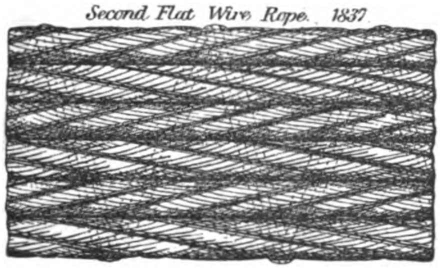
The formed wire ropes possessed great pliability and some amount of elasticity; they were readily spliced and fitted like ordinary ropes, and though not so strong as the selvagee wire ropes, they possessed many advantages and were more easily introduced. The small size and soft nature of the wire used offered little resistance to exterior friction, and when employed as incline or running ropes they soon flattened and wore out. The irregularity with which the wires were formed or twisted into strands, frequently crossing and recrossing one another, and the great difference in the length of the wires, as well as the short lay of the ropes, amounting to only 4½ in. pitch, materially assisted to destroy them. Even when used simply as standing rigging, the wires frequently broke, and the broken ends stuck outwards to the danger of the sailors handling the rigging; and to prevent accidents they were served with yarn, like the selvagee rope, after having been wormed, that is, having a yarn laid in between each strand so as to alter the shape to a round form.

The first flat wire ropes, Figs. 6758, 6759, were composed of from eight to twelve formed strands, with the twist alternately right and left handed, made of a number of fine wires usually about 18 or 20 wire-gauge, or 0·050 to 0·036 in. diameter. These strands were placed in the position of the warp, in a loom of the ordinary form but greater strength, and were woven together with a shoot of strong

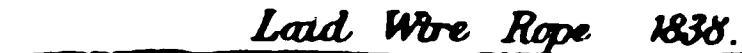
yarn. Very little twist was put into the strands, as the yarn when woven in kept them in form. These ropes were by no means durable, as the yarn soon wore out, especially at the edges; and their application was very limited.

Flat wire ropes were next made of four or six formed ropes, each made of four strands laid very long, and alternately right and left handed; these were stretched together side by side and sewn through with six wires of No. 14 or 16 wire-gauge from side to side in a zigzag direction, as in Figs. 6760, 6761. This was accomplished by carefully inserting a needle of dagger shape between the strands of the ropes, and so making a passage for the wires, which were carefully laid side by side. The round ropes thus bound together resembled the ordinary flat hemp rope in appearance. The process was tedious, on account of the care necessary to avoid penetrating the strands with the needle, which would do great injury to the rope.

6760.



6761.

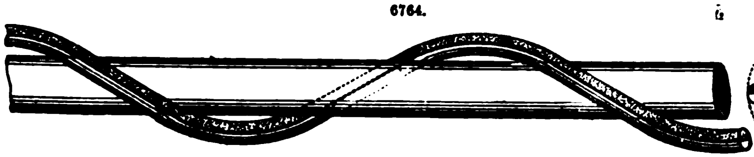


6762.

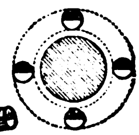
6763.

The last construction of wire rope is known as laid rope, Figs. 6762, 6763, in which the strands were made of a few wires, seldom exceeding six, laid around a core of hemp or wire, the wires of the strand being entirely free from twist, each wire being simply laid in a spiral form without any twist in the wire itself, as shown in the diagram, Figs. 6764, 6765. Six of these strands were again laid

6764.



6765.



without forehard or additional twist into a rope, around a core generally of hemp. The size of wire usually varied with the size of the rope, as the total number of wires, 36, was seldom varied. The wire was hard or unannealed; and by the system adopted in making, a uniform length was obtained with entire absence of twist. By this means the full strength of the wire was retained, and consequently the rope produced was much stronger for the same weight. An increase in size is, however, caused by the introduction of the hemp cores, which amount to one-seventh of the entire bulk in the case of ropes with six strands of six wires each, the construction now usually adopted.

The machinery used in the manufacture of laid strands and ropes originally consisted of the ordinary machinery used on rope-grounds for laying or closing hemp ropes, the machines at each end of the factory being speeded alike, as previously described.

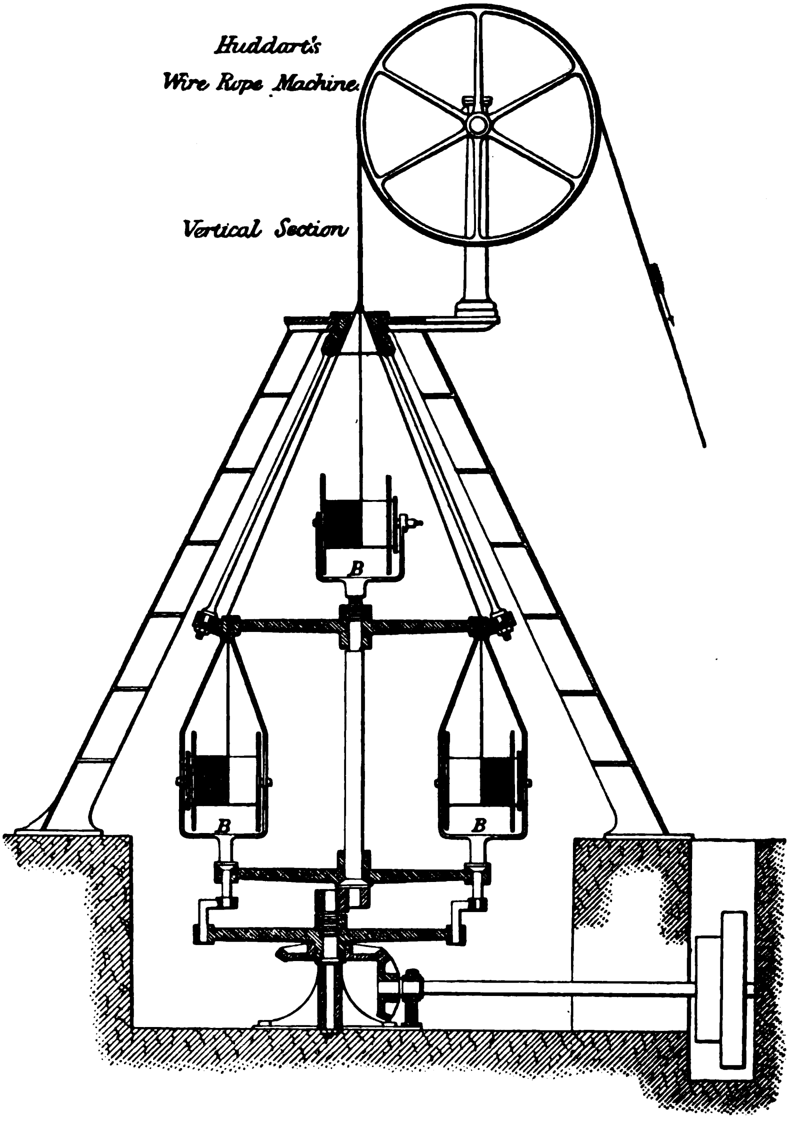
The next form of machine adopted had simply one hook, mounted in bearings on a fixed frame, and driven by hand or power, to which all the wires composing the strands were attached; these were stretched along the ground, supported at intervals on trestles, till they reached the other end, where they were hooked on to swivels or lopers. Attached to the lopers were cords passing over pulleys and having weights suspended from them, so as to regulate the tension of each wire, and also allow for the shrinkage of the rope in the process of making. When the hook was set in motion, the twist in each wire traversed the entire length of the wire, and escaped at the end by means of the loper or swivel. A perforated plate or laying top was used, carried by a workman along the ground, regulating the amount of lay or twist.

The next machine used, shown in Fig. 6766, was a modification of Huddart's hemp rope-laying machine, previously described. In these machines the operation went on continuously until the required length of strand or rope was made, giving rise to the name of endless machines; they were also called vertical machines, because the main frame carrying the spools revolves on a vertical axis. The first modification of this machine for making wire ropes consisted in altering the gearing for working the spool-frames B, so that no additional twist or forehard was put in the wires as in the strands of hemp ropes, the pinions on the spool-frames being now made of exactly the same diameter as the central dead-wheel, as in the diagram, Fig. 6767, causing the spool-frames to make exactly one rotation on their axes for each revolution of the machine. Machines of this description were also made to work on a horizontal axis instead of a vertical one; and a balance weight was sometimes attached to each spool-frame in the horizontal machines, which by its gravity prevented the spool from twisting the wire, and rendered gearing unnecessary for the purpose; but the speed of these machines was limited in consequence.

Another machine was that known as a compound machine, for producing the entire rope finished at one operation; and may be described as consisting of six stranding machines, like that last described, all mounted on one large frame and revolving horizontally, the necessary motion being given to the machinery to lay the wires into strands and then the strands into rope, without producing any twist in the individual wires. This machine, though a mechanical success, was a commercial failure, and was soon abandoned for the simpler and cheaper plan of first making the strands and then laying them into ropes on separate machines.

Some modification was then made in the vertical machines, Fig. 6766, in the means of preventing twist of the wires during the laying, by employing a centre crank or eccentric and four

6766.



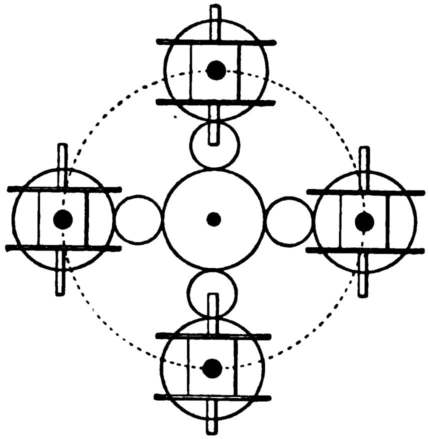
outer cranks on the spool-frames B, Fig. 6766, and in the diagram, Fig. 6768, and also by substituting chain wheels and pitch chain, Fig. 6769.

The method of joining the lengths of wires was in the first instance by twisting the ends together; afterwards, in the manufacture of laid strands, by tucking, that is cutting out the hemp core about 12 in. from the end of the wire that has run out, and inserting in its place the end of the new length of wire; the rest of the wires are then laid up on the new wire as a core for a length of 6 in., when the new wire is brought out into its right place and the remaining 6 in. of the old wire passed in as the core, on which the laying is again continued till the end of the wire is reached; the proper hemp core is then replaced, and the process of laying resumed as before. Some manufacturers prefer to braze or weld the ends of the wires together for joining the lengths, wire as small as No. 16 wire-gauge, or 0·065 in. diameter, being welded by experienced workmen by means of a common portable forge.

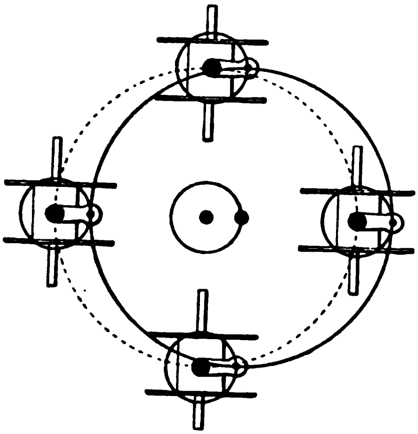
In Archibald Smith's wire-rope machine the bobbin-frames and bobbins are placed one behind another all in the axis of the revolving frame, and remain stationary in that position while the frame alone is made to revolve.

Smith's machine is shown, Figs. 6770 to 6773. Fig. 6770 is a side elevation of the entire

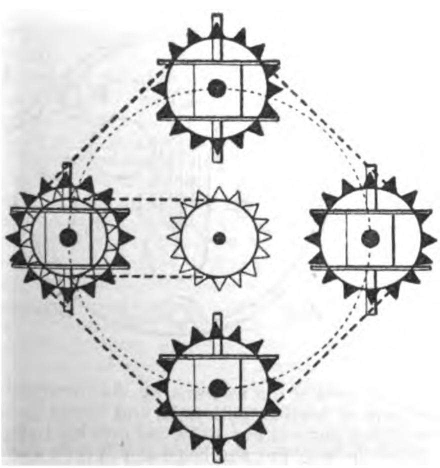
6767.



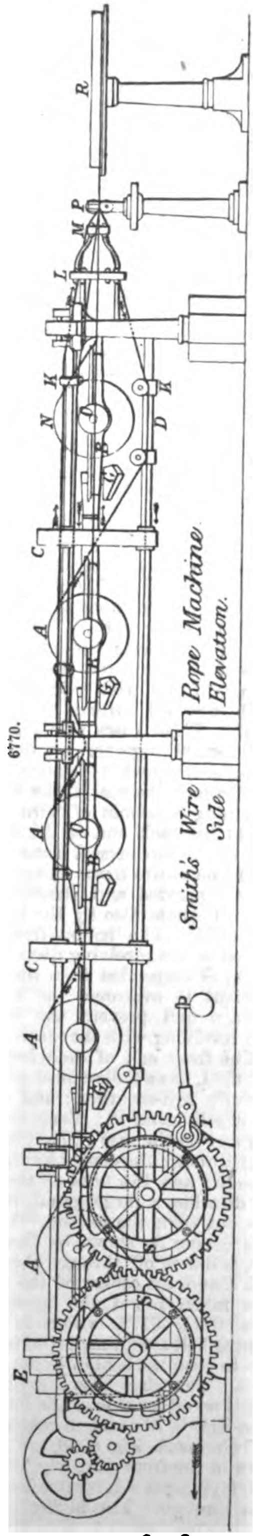
6768.



6769.



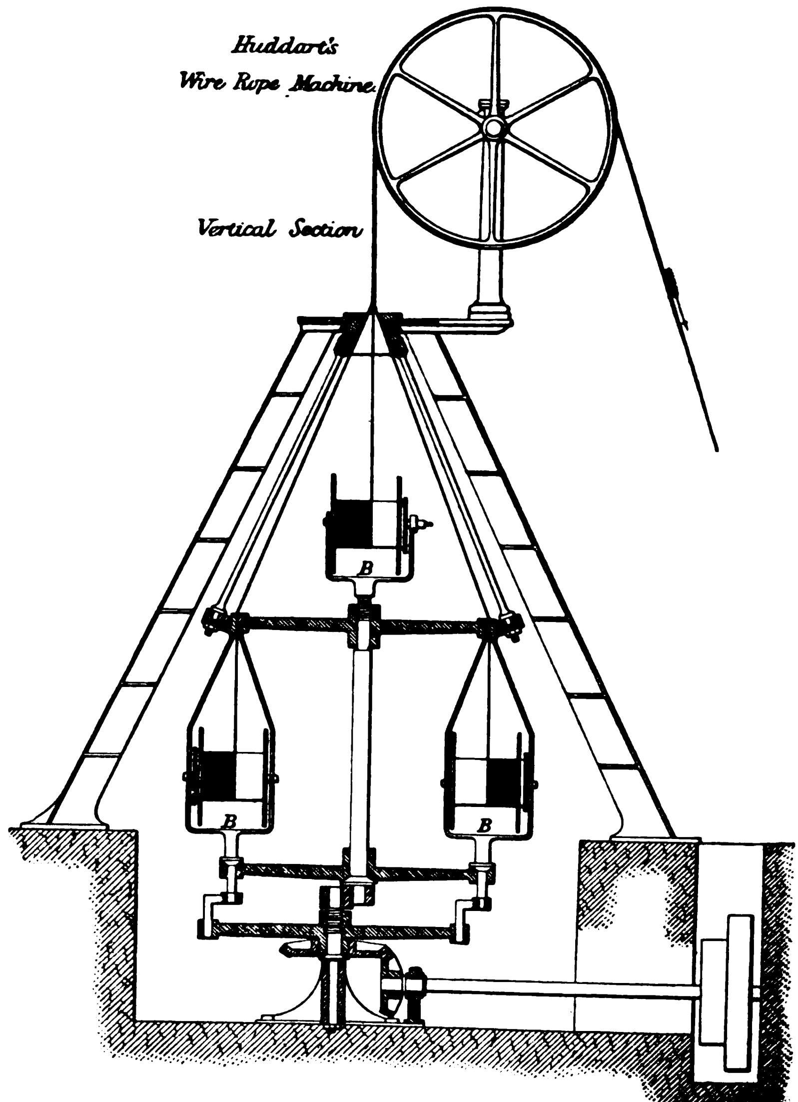
6770.



Smith's Wire Rope Machine Side Elevation.

Some modification was then made in the vertical machines, Fig. 6766, in the means of preventing twist of the wires during the laying, by employing a centre crank or eccentric and four

6766.

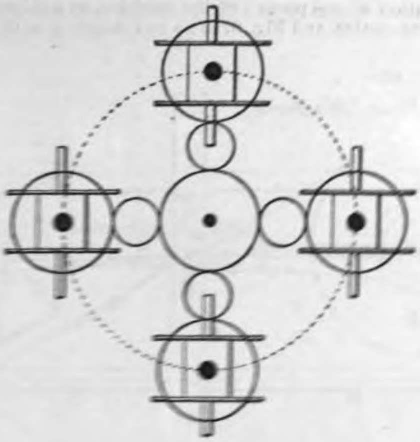


outer cranks on the spool-frames B, Fig. 6766, and in the diagram, Fig. 6768, and a[illegible]
stituting chain wheels and pitch chain, Fig. 6769.

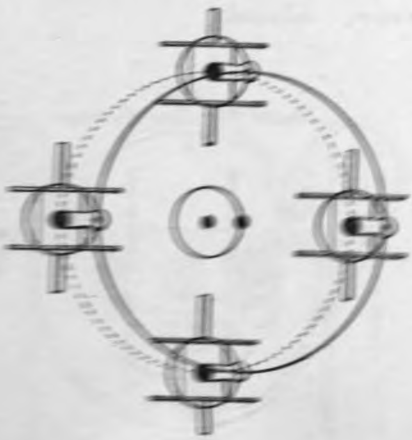
The method of joining the lengths of wires was in the first instanc[illegible]
together; afterwards, in the manufacture of laid strands, b[illegible]
core about 12 in. from the end of the wire that has run [illegible]
the new length of wire; the rest of the wires are the[illegible]
a length of 6 in., when the new wire is brought out int[illegible]
the old wire passed in as the core, on which the layi[illegible]
is reached; the proper hemp core is then replace[illegible]
Some manufacturers prefer to braze or weld the [illegible]
wire as small as No. 16 wire-gauge, or 0·065 i[illegible]
by means of a common portable forge.

In Archibald Smith's wire-rope machine [illegible]
another all in the axis of the revolving fr[illegible]
frame alone is made to revolve.

Smith's machine is shown, Figs. 67[illegible]



6767.

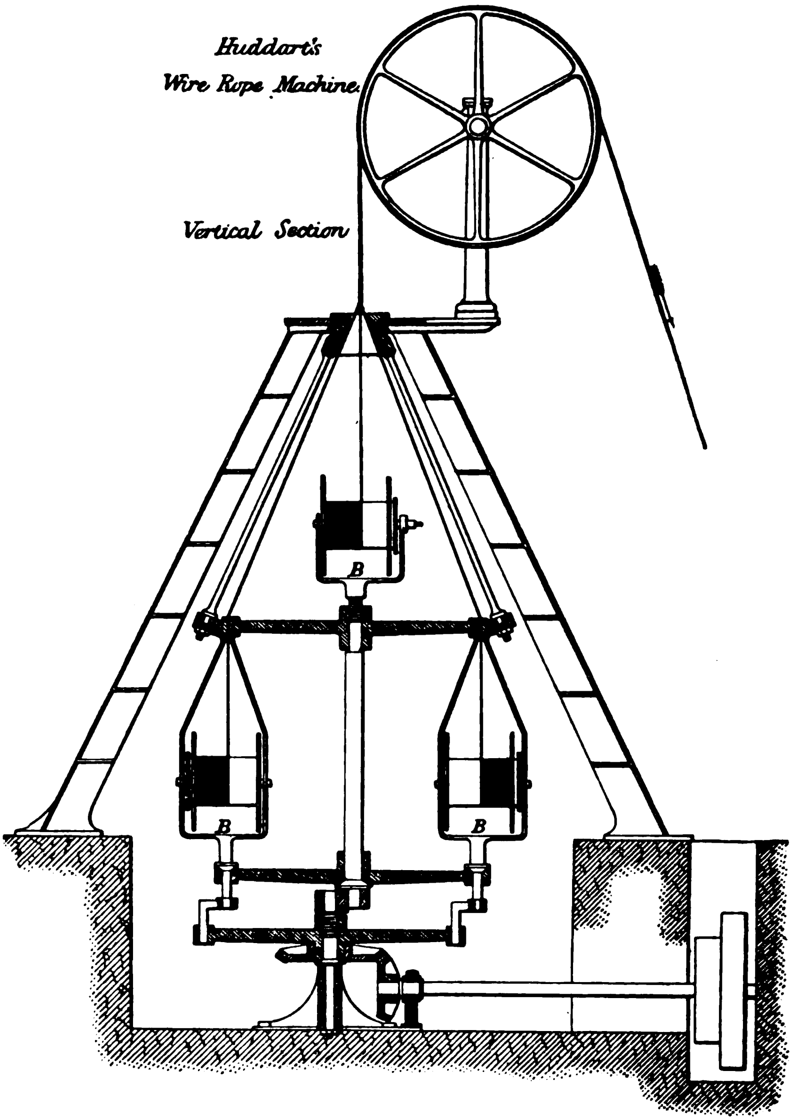


6768.

6770.

Some modification was then made in the vertical machines, Fig. 6766, in the means of preventing twist of the wires during the laying, by employing a centre crank or eccentric and four

6766.



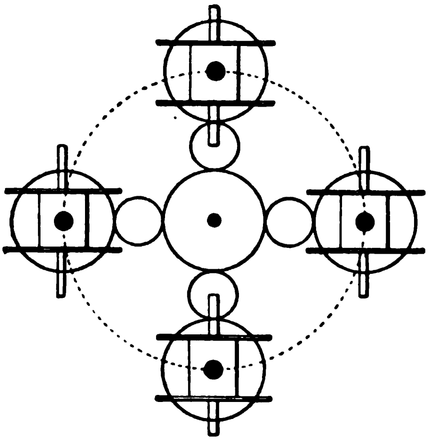
outer cranks on the spool-frames B, Fig. 6766, and in the diagram, Fig. 6768, and also by substituting chain wheels and pitch chain, Fig. 6769.

The method of joining the lengths of wires was in the first instance by twisting the ends together; afterwards, in the manufacture of laid strands, by tucking, that is cutting out the hemp core about 12 in. from the end of the wire that has run out, and inserting in its place the end of the new length of wire; the rest of the wires are then laid up on the new wire as a core for a length of 6 in., when the new wire is brought out into its right place and the remaining 6 in. of the old wire passed in as the core, on which the laying is again continued till the end of the wire is reached; the proper hemp core is then replaced, and the process of laying resumed as before. Some manufacturers prefer to braze or weld the ends of the wires together for joining the lengths, wire as small as No. 16 wire-gauge, or 0·065 in. diameter, being welded by experienced workmen by means of a common portable forge.

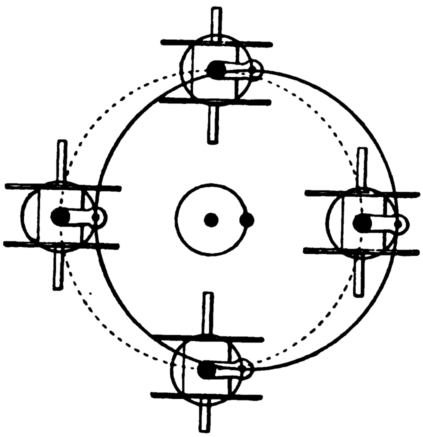
In Archibald Smith's wire-rope machine the bobbin-frames and bobbins are placed one behind another all in the axis of the revolving frame, and remain stationary in that position while the frame alone is made to revolve.

Smith's machine is shown, Figs. 6770 to 6773. Fig. 6770 is a side elevation of the entire

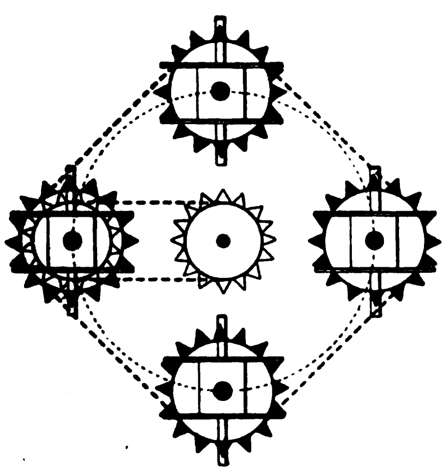
6767.



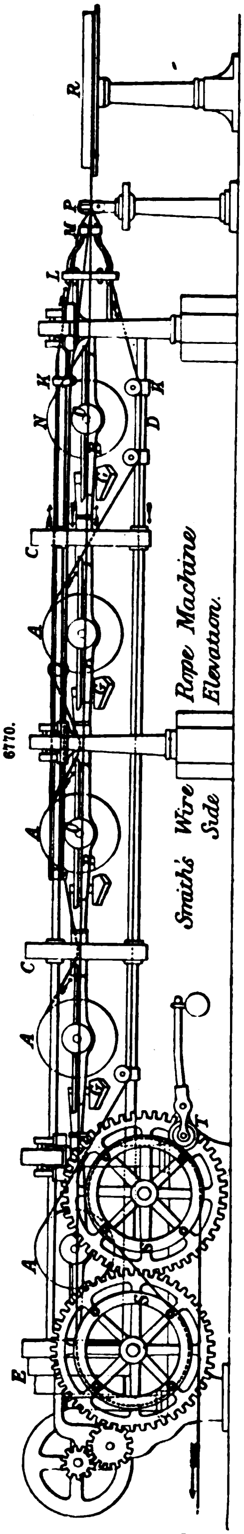
6768.



6769.

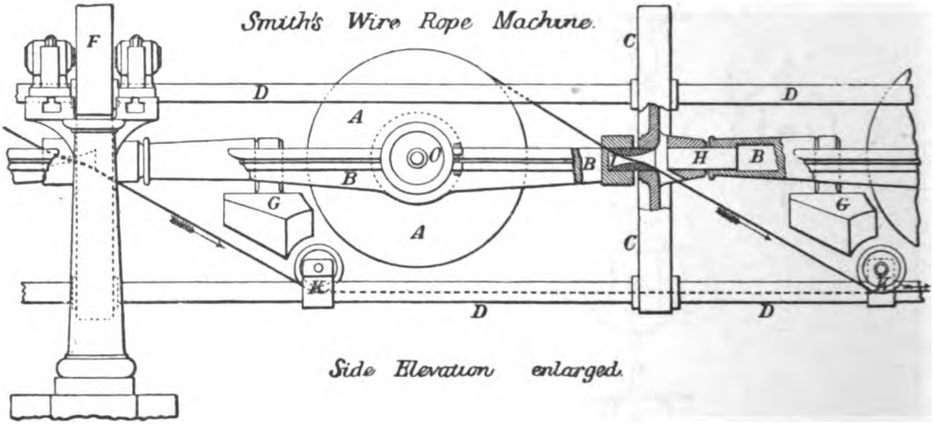


6770.



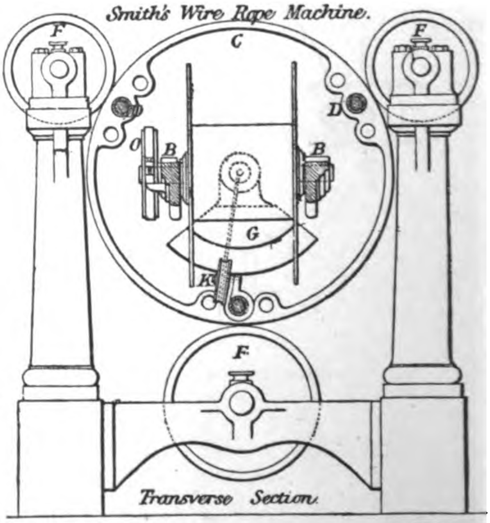
length of the machine. Fig. 6771 a side elevation of one portion of the machine, to a larger scale and partly in section. Fig. 6772 is a transverse section, and Fig. 6773 an end elevation at the front end of the machine.

6771.

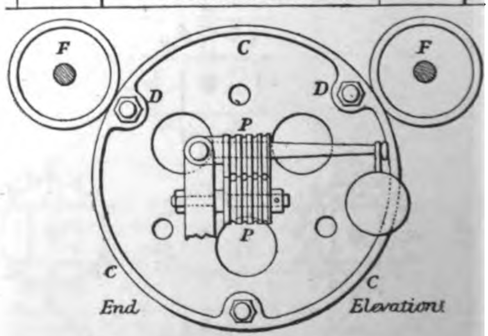


The bobbins A, A, Fig. 6770, are here all arranged in a horizontal line one behind another, in the axis of the revolving frame of the machine. The revolving frame is composed of a number of disc-wheels C, C, framed together by three long bolts D, Figs. 6771, 6772, passing through holes near the edges of the discs and through strong iron distance tubes with collars at each end, which are all turned accurately to one length. Eight discs C, C, Fig. 6770, are thus framed together by the three bolts, and separated by the distance tubes, forming seven compartments of the machine, each containing a bobbin of wire A. The last disc at the back end of the machine forms part of a three-speed cone-pulley E, by which the entire frame is made to revolve, being supported and steadied sideways at every alternate disc by the three rollers F, Fig. 6772. The bobbin-frames B, B, are centred in the revolving discs C, and have a weight G suspended from their under side, sufficient to overcome the friction of the bearings and prevent the bobbin-frames from revolving with the machine.

6772.



The front end of each bobbin-frame B, Fig. 6771, has a hollow steel stud or nipple I, carefully bell-mouthed; and the back end has a solid stud H. Each stud works in a boss cast on the disc C, having a clear hole right through the centre for the wire to pass through; and the boss on the front side of the disc has a large gap J, for the wire to pass out from the centre. The wire from each bobbin A, shown by the strong black line, is drawn off through the bell-mouthed stud I and the centre of the disc C, and is then taken round the leading pulley K, Figs. 6771, 6772, which is fixed on the framing bolt D for the purpose of enabling the wire to clear the bobbin in the next compartment. The wires pass through holes in the disc C on either side of the framing bolts D, as in Fig. 6772; and on reaching the front compartment of the machine, all the six wires from the six bobbins A, Fig. 6770, are led round three pairs of leading pulleys K, and thence through the holes in the front disc, Fig. 6773, through the laying plate L, Fig. 6770, and over the laying top M. The laying plate L is attached to the front disc of the machine, and has a slot in it for each wire to pass through. The laying top M fixed in front of the laying plate is simply a cast-iron block



6773.

with the required number of scores or grooves for the wires. The front bobbin N, Fig. 6770, in the first compartment of the machine, carries a seventh wire to form the core for the six external wires, which is led off through the centre of the front disc and through a hole in the centre of the laying plate L and laying tap M. The tension or temper of each of the seven wires is regulated to the exact amount required by a friction-brake O on the spindle of each bobbin, Fig. 6772. The bearings of the spindle in the bobbin-frame B are provided with spring caps, to facilitate changing the bobbins.

The six wires are all brought together at a point immediately in front of the laying top M, where they are all laid round the core by the revolution of the machine, the bobbins A remaining stationary with the exception of their unwinding motion as the wires are drawn off; each wire is thus laid into the strand free from twist in itself. The strand thus made passes between the nipping rollers P, Fig. 6773, which have a series of scores of different diameters to suit various sizes of strand or rope; the lower roller turns on a fixed stud, and the upper one on a weighted lever. The strand is then led half round the indicator sheave R, Fig. 6770, which has a counter attached to indicate the number of yards or fathoms made. Thence it passes backwards alongside the machine to the draw-off wheels S, S, at the back end; these are V grooved wheels of equal diameter, round which the strand passes in a figure of 8 course, being pressed tight into the groove of the second wheel by the tightening roller or jockey-wheel T, which prevents the strand from slipping from any accidental cause. The draw-off wheels S are driven from the driving pulley E by intermediate bevel-gearing, with a change-wheel by which the speed of the draw-off wheels is regulated in proportion to the speed of revolution of the machine, whereby the lay of the wires or pitch of the spiral in the strand is determined. The strand finally leaving the machine from the draw-off wheels is wound on a bobbin, ready to be placed in a second similar machine to be laid into rope. In this second machine the revolution of the laying apparatus is in the opposite direction, while that of the draw-off wheels is in the same direction as in the first machine, in order to make the lay of the strands in the rope contrary to that of the wires in each strand. From the second machine the rope is coiled on a reel, or in case of its being a long length it is sometimes coiled down direct into trucks for transportation.

In this machine, instead of the bobbins and bobbin-frames, which sometimes contain half a ton weight each, being carried round the common centre of the machine, sometimes describing a circle of 15 ft. diameter, and also rotating on the axes of the bobbin-frames once for every lay in the rope, the same result is attained without any motion being given to the bobbin-frames. This is an important advantage, because in course of working some of the bobbins are full while others are nearly empty, and in the case of the old machinery a great strain is thereby thrown on the parts of the machine from the variation in weight; while in the construction just described the equilibrium of the machine is never disturbed. In addition to this, great regularity of lay results from the wire being free to unwind, and from the absence of the extra tension that was necessary to prevent the wire being disturbed when rapidly carried round in the old machine. The stationary position of the bobbins enables the workmen to see what is going on, and no entanglement of the wire takes place, as is frequently the case in other machines.

ROTARY ENGINE. Fr., *Rotatoire-machine*; Ger., *Dreh-Maschine*; Ital., *Macchina rotatoria*; Span., *Máquina rotatoria*.

See Engines, *Varieties of*.

SAFETY-VALVE. Fr., *Soupape de sûreté*; Ger., *Sicherheitsventil*; Span., *Valvola di sicurezza*; Span., *Válvula de seguridad*.

See Details of Engines.

SAW. Fr., *Scie*; Ger., *Säge*; Ital., *Sega*; Span., *Sierra*.

See Wood-working Machinery.

SCAFFOLDING. Fr., *Échafaudage*; Ger., *Rüstung*; Ital., *Ponte*, *Castello*; Span., *Andamiaje*.

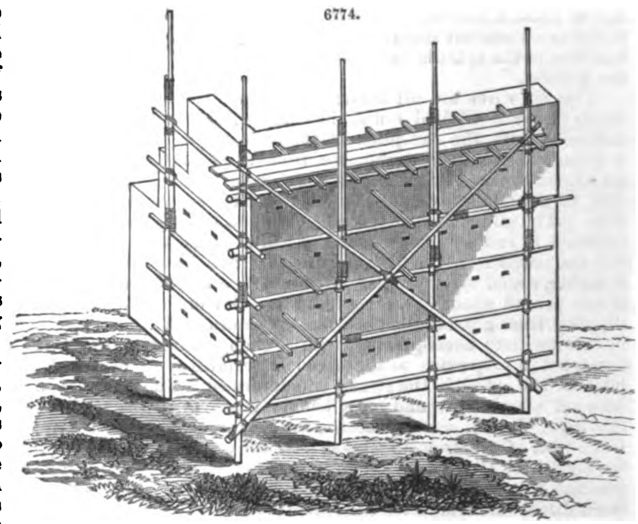
Scaffolds, Staging, and Gantries.— A scaffold as used in building is a temporary structure supporting a platform, by means of which the workmen and their materials are brought within reach of the work.

The most common form of scaffold is that used by the bricklayer. It consists of poles, usually of fir, from 25 to 40 ft. in length, and from 6 to 8 in. in diameter at the butt or larger ends. These poles, which are called standards, are planted in a row at intervals of 10 or 12 ft., and at a distance from the wall to be erected of about 5 ft. in the clear. To the standards on the sides next the wall other poles called ledgers, placed horizontally, are lashed with ropes as the work proceeds, at intervals of about 5 ft. in height. These support the putlogs, which are pieces of squared timber about 6 ft. long, and from 4 in. by 3 in. to 4 in. by 3½ in. in scantling. The putlogs are supported at one end on the ledgers and the other on the wall, a header or half-brick being left out for the purpose in building. Putlogs are usually placed at about 3½ or 4 ft. apart. On them are laid the scaffold boards, which are about 9 in. wide by 1½ in. thick. It is on these scaffold boards that the workmen stand, and the bricks and mortar are deposited. Fig. 6774 shows the arrangement of a bricklayer's scaffold. When the scaffold has to be carried to a considerable height other poles are lashed to the standards with ropes tightened by wedges. Poles are also lashed diagonally across every three or four standards in the shape of a St. Andrew's cross; these are called braces, and they serve to stiffen or brace the scaffold longitudinally.

In buildings which do not admit of putlog-holes in the walls, as where rubble stone or ashlar facing is used, and which do not require heavy machinery for hoisting, or strong timbers in the scaffold, two rows of standards with ledgers are used, one row being close to the wall, and the other at the usual distance, so that both ends of the putlogs may rest on the ledgers. Scaffolds such as we have just described are sometimes used for heights of 90 or 100 ft. from the ground, as in building church steeples and similar work. In the erection of houses it is usual to construct a staging about 10 ft. square on the outside of the scaffolding, for the purpose of hoisting materials, and from which they are distributed for use. This staging is usually formed with standards and

ledgers in the same manner as the scaffold to which it is connected. In the erection of large works in masonry, the materials used being blocks of stone, frequently weighing several tons, it is obvious that a different arrangement is required from that where the materials can be lifted and set by the hands of the workmen, as in the case of bricks and the small stones used in rubble-work. The mason therefore uses, instead of a scaffold formed of round poles, one of squared timbers of large scantling, which being too large to be lashed with ropes, are fastened together by bolts and dog-irons, and are kept quite independent of the walls, putlog-holes as used in brickwork being inadmissible.

6774.



The standards were formerly planted in two rows, one being next to the wall, and a boarded platform was carried on the top similar to the bricklayer's scaffold, the heavy stones being hoisted and set by means of shears with blocks and tackle. This method is now almost superseded in large works by a staging formed of squared timbers, in the same manner as the mason's scaffold, but with only one row of standards on each side of the wall. On these standards are laid the longitudinal timbers, which usually carry a line of rails on which a travelling platform containing the hoisting gear can move over the entire extent of the building. The standards and longitudinal timbers are made perfectly rigid by struts, disposed as in Fig. 6775, which is a front view of one tier of the outer row of timbers.

The standards A, A, are in scantling usually from 8 to 12 in. square, according to the height of the scaffold and the weight to be supported. The distance apart is from 10 to 20 ft. Corbel or cap-pieces B, B, are placed under the longitudinal timbers or runners C, C, to give the latter a better bearing on the heads of the standards. The runners C, C, are usually of the same scantling as the standards; but the struts D, D, are seldom more than one-half the sectional area of the standards. These struts usually pitch against a straining piece E, which is bolted to the under side of the runners. The lower ends of the struts rest on cleats, and are secured to the sides of the standards either by iron spikes or bolts. It is desirable to have as few bolt-holes as possible, and to avoid notching, mortising, or otherwise cutting into the timber, so that the deterioration in value at the completion of the work may be as little as possible. Therefore the several pieces are for the most part put together with dog-irons, which are pieces of square or round iron about ¾ in. in diameter, having the ends pointed and turned down at right angles. These are driven into the wood, and can be removed with little or no injury to it afterwards.

The distance at which each row of standards should be placed from the wall will depend upon the general arrangement for conducting the works. In some cases a tramway leading from the quarry or stone depôt is laid between the outer row of standards and the wall to admit of the stone being lifted directly from the truck on to the work. In this case a space of from 10 to 20 ft. would be required between the standards and the wall. In other cases, as in the streets of towns, or where the space is limited, the timbers are placed within a few feet of the wall on both sides, and the materials are lifted at some convenient part of the work, over which the traveller with its hoisting gear can be brought. Fig. 6776 shows a section of a wall in progress with the travelling platform resting on the staging.

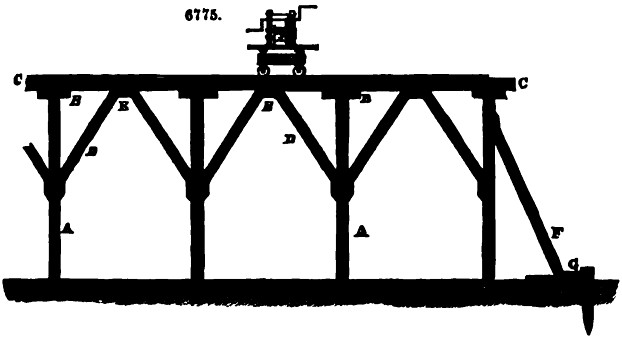
To prevent lateral movement in the staging, struts from the ground, as F, Fig. 6776, are usually fixed to each standard. The lower ends of the struts should always be fixed to foot-blocks, as at G, by which they are prevented from sinking into the ground. A short pile should be driven at the outer end of the foot-block, which will prevent it from slipping. The usual practice, however, is that shown by Fig. 6777, in which the foot-block is sunk in the ground at right angles to the direction of the strut. The choice of these methods will depend on the nature of the ground. Sometimes the ends of the standards are framed with a short or stub tenon into a continuous sill of timber placed on the surface of the ground; this prevents the unequal settlement of the standards, which would be fatal to the stability of the staging.

In the foregoing description the staging is supposed to be in one tier only; but in buildings which have to be carried to a great height the staging will require to be raised accordingly. This is usually accomplished by placing a beam of timber across the head of each standard, and projecting some 9 or 10 ft. beyond it at right angles to the direction of the runners on which it is made to rest, as I, I, Fig. 6777. This piece, which is called a footing piece, serves the same purpose as the foot-block G, Fig. 6776; but instead of resting on the ground, it is supported by the struts H, H, Fig. 6777. These struts are usually in two pieces in order that the struts F, F, may pass between them.

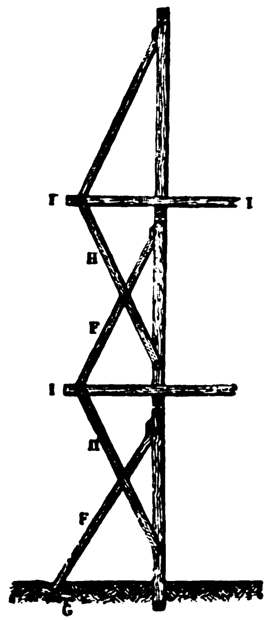
The standards of the upper tiers should always be placed directly over those of the lower tiers to prevent cross strains on the horizontal timbers. Figs. 6777, 6778, show the principle generally

adopted for staging of this kind, the upper tier being usually braced by diagonal braces, as shown in Fig. 6778.

6775.

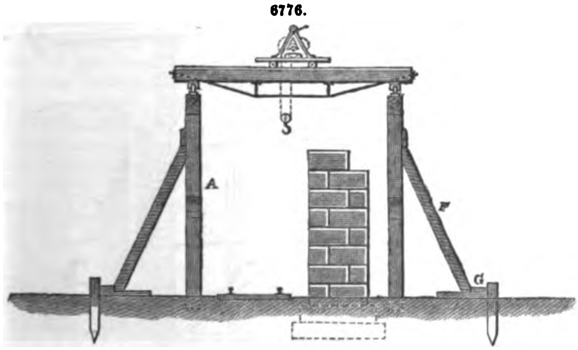


6777.

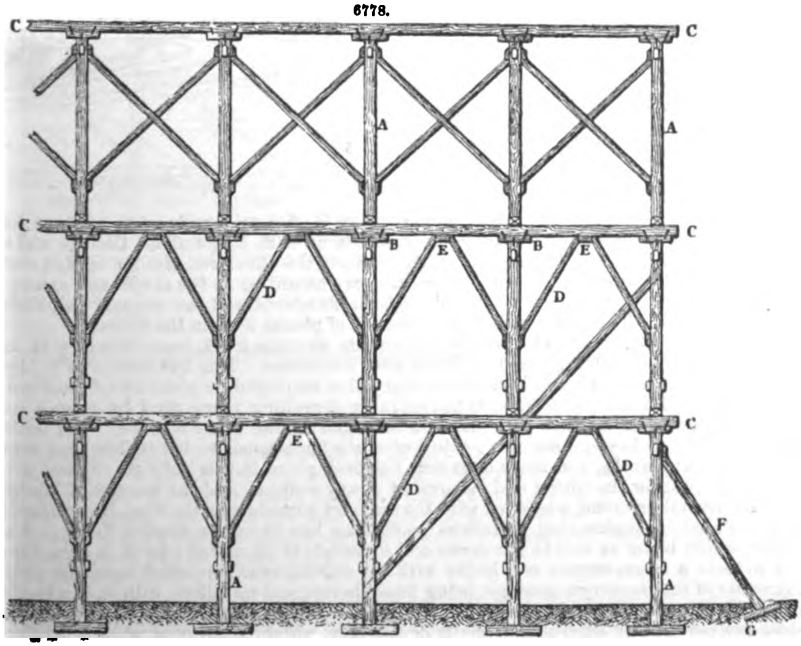


Section.

6776.



6778.



Elevation.

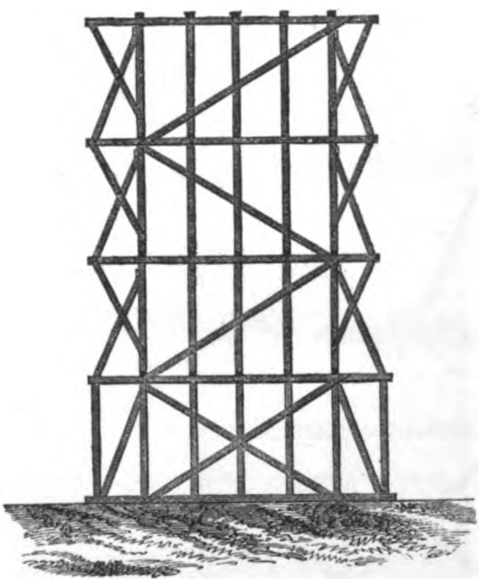
The term gantry is frequently applied to a structure of timber, such as we have described; but properly a gantry is a staging which carries a traveller only, as that shown by Figs. 6775, 6776.

Fig. 6779 is a transverse section showing the arrangement of the timbers of a staging as used in the construction of bridges and viaducts. The width should be from 10 to 20 ft. more than the width of the bridge, and the height of the staging is usually about the same as the springing line of the

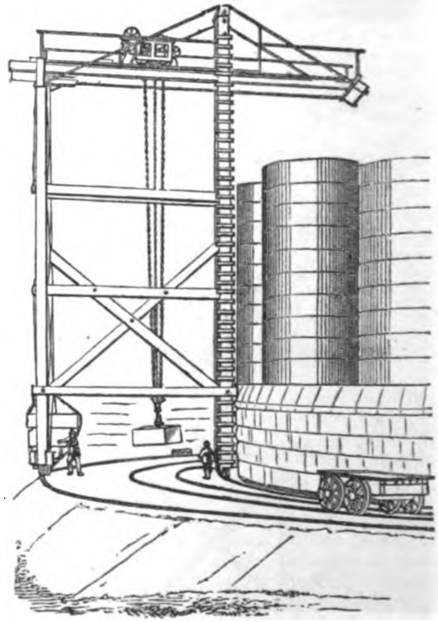
arch. A line of rails is generally laid on each side to admit of a traveller called a Wellington, which is similar to that shown by Fig. 6776, but with the addition of legs to make it clear the upper portion of the structure over which it passes. By means of this traveller all materials, whatever their weight may be, can be hoisted from the ground with the greatest facility, and deposited in the position they are to occupy in the work. In brick arches or those of rubble stone such a traveller would not be required.

In viaducts of great height a staging, as Fig. 6779, is also used to support the centering, or in those formed of iron the girders are put together on it. That used in constructing the land tubes of the Britannia Bridge in 1850 was similar in principle to the staging shown by Fig. 6779. When the arches are of considerable span, two or more of the frames shown by Fig. 6779 are required for each arch; they are connected by longitudinal timbers or runners, on which the rails are laid strutted, Fig. 6775; or when the distance between the supports is great, wrought-iron tie-rods are used as for purlins. Where centering has not to be supported, or in an iron bridge where the girders are not put together in position, a simple gantry, Figs. 6777, 6778, to carry a traveller is all that is required.

6779.



6780.



The scaffolding used in the erection of domes and roofs of considerable span, as those for large railway stations, is nothing more than a series of standards with longitudinal timbers, and a platform on the top with diagonal braces and struts between the standards, similar to that shown by Fig. 6779. The arrangement or plan will of course vary according to the shape and extent of the building. Whole timbers are generally used for both standards, and runners and half-timbers for the struts and braces. The platform is usually formed of planks 3 in. in thickness.

Fig. 6780 represents the movable scaffolding and its circular track, constructed by H. Lee and Sons, and employed in building Garrison Point Fort, Sheerness. This traveller is 46 ft. high from rail to rail; the tramway or track is of the ordinary kind employed for stone travel; extreme width 18 ft., length of sill 24 ft. The crane is the ordinary travelling crane used by masons and contractors; the transverse carriage and crab are arranged in the usual manner. The economy of manual labour in working cranes is a subject of much importance to the builder and contractor, especially for heavy works, and much attention has been given to this subject. Steam power has been long employed for the lifting and removal of heavy weights, and the amount of labour saved by the steam travelling crane, compared with the ordinary hand-labour machine, is considerable. In many of our modern engineering operations scaffolding has to be constructed to support a small steam-engine and boiler as well as the crane and materials to be moved; for it is often found convenient to have a steam-engine and boiler with the driving gear supported upon the platform at one extremity of the transverse carriage, being fixed thereto, and travelling with it, in a longitudinal direction, whenever so required. In this way the steam power travels with the traversing carriage, and does not require any longitudinal shafts or bearings, which is the case when a fixed engine is employed, the lubrication and friction of the longitudinal shafting being also saved.

Figs. 6781, 6782, show a sketch of the staging used by the contractors, Lee and Sons, in the construction of the Admiralty Pier at Dover, in a depth of water of over 60 ft. at high spring-tides. This staging carried a pair of travellers on rails 37 ft. 10 in. apart, and also two tramways of 4 ft. 10 in. gauge for the trollies which carried the materials to run on, one being on each side of the travellers.

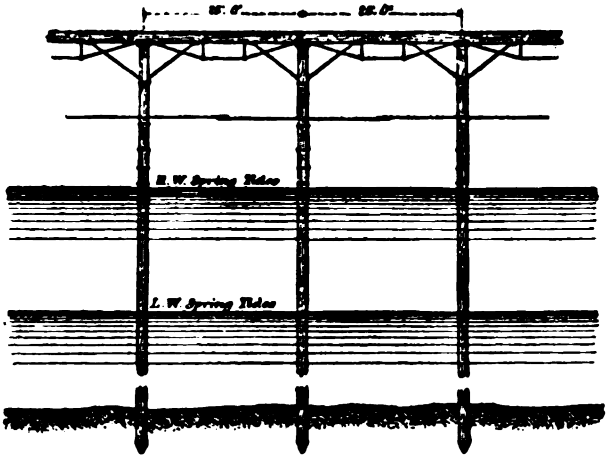
The staging was supported on three rows of piles, from 17 to 20 in. diameter, and about 90 ft.

long, but with one splice in each pile above the high-water level. The splices were made good with wrought-iron bands and straps. The piles were shod with iron, and driven into the ground at intervals of 25 ft. from centre to centre, and the distance between each row was about 41 ft.

The transverse beams, which were of whole timbers, were in two thicknesses, one above the other, and were secured to the heads of the piles by iron sockets bolted on. Over the transverse beams were laid the runners; those for the traveller rails were formed of two whole balks placed side by side. The tramways were supported by single balks of the same size. A footway about 4 ft. 6 in. in the clear was formed in the middle of the stage by planking over the space between the runners of the adjoining traveller ways.

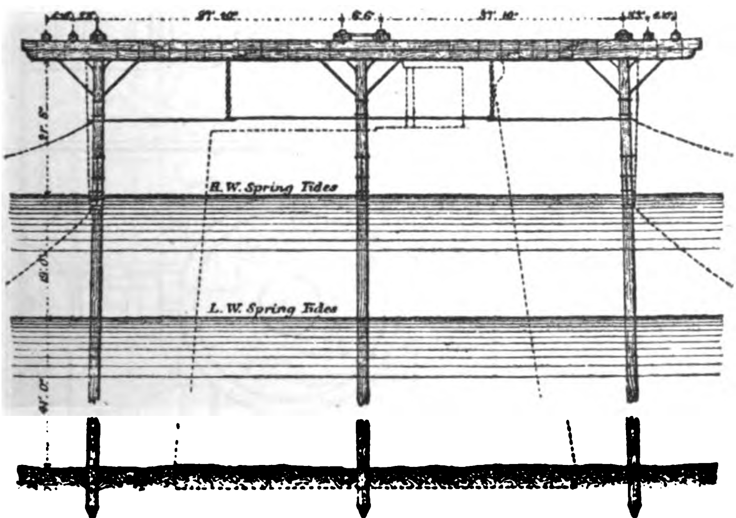
As the staging was liable at times to the wash of a very heavy sea, it was the object of the contractors to construct it so as to offer as little obstruction to the waves as possible, therefore the ties and braces were all made of wrought iron, as shown by the thick black lines

6781.



Longitudinal Section.

6782.



Transverse Section.

in the drawing, and the piles were rounded with the same object. From the great length of the piles under water it was difficult to introduce efficient bracing, consequently to each pile of the outside rows a pair of mooring chains were attached and anchored in the sea, one at a distance of about 490 ft. from the foot of the pile, and the other at about 290 ft.

It is rarely that we find a staging erected in such deep water, and it reflects much credit on the skill of the contractors who carried it out.

SCREW ENGINES.

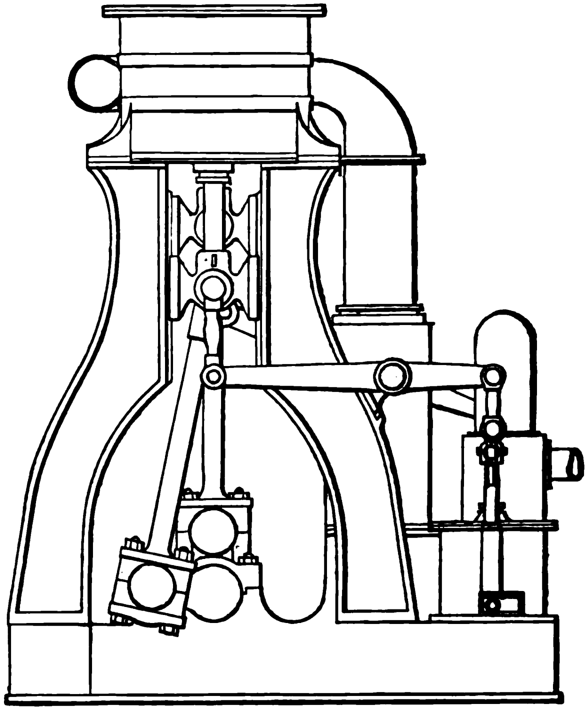
The chief difference between marine engines adapted to drive paddle-wheels, and those suited for giving motion to the screw is, that in the latter case the engines are direct acting, whilst in the former they are not always direct acting, but the motion is conveyed through the intervention of side levers.

The overhead arrangement of the cylinders, Figs. 6783, 6784, is very common with screw engines built in the north of England, and any variation in their design and position is usually due to the particular variety of condenser adopted.

Figs. 6783, 6784, represent a pair of engines with injection-condensers. The cylinders are supported on standards similar to a girder. The slide-valves are between the cylinders, but ample space is allowed for necessary inspection. The supply steam pipe is attached to the casing at

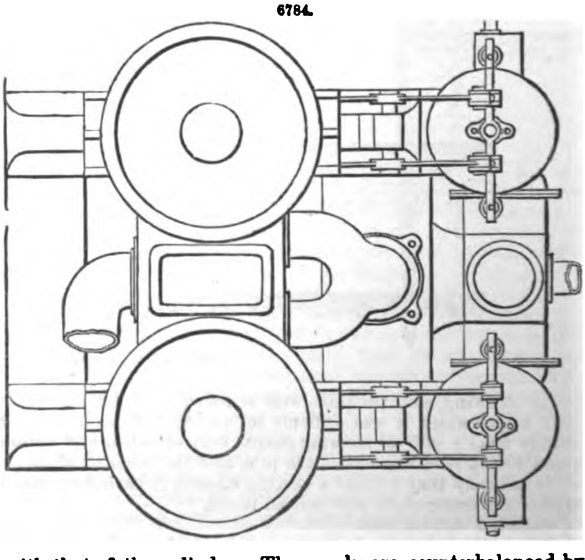
the side, the exhaust-pipe being situated opposite. This latter pipe forms two separate connections at the top, with a single connection at the end secured to the condenser. The expansion and contraction of this pipe is effected by the stuffing box seen on the condenser. The air-pumps and valve-chambers are secured beyond the condenser. Motion is imparted by levers connected at the one end to links on each side of the connecting-rod pin; the other end being in like manner secured to the cross-head which is connected direct to the air, feed, and bilge pumps' rods.

6783.



Side guides are sometimes used for the pump cross-head, but are not always used with short strokes and stiff gear. The injection-valve is secured below the exhaust steam pipe, between the condenser and the air-vessel, the latter being on the discharge-chamber. The final discharge-water pipe is secured to the outside of the chamber, and from thence to the ship's side. The guide-blocks for the engine piston-rods are of the ordinary kind, with flat surfaces and adjusting pieces. The connecting rod is of the usual type and connection. The base or lower framing is similar to box-girder in section, also forming a portion of the condenser and valve-chambers at the side. The valve link motion is between the engines. The means for starting, stopping, and reversing, are attained by a hand-wheel, worm, pinion, and levers. The cranks and shaft are in one forging, the bearings being fitted with adjustable brasses.

6784.



Double Trunk-engines.—The object to be attained by trunk-engines is compactness of arrangement, with free space above the cylinders and condensers.

Figs. 6785, 6786, represent an arrangement of double trunk-cylinder screw engines by J. Penn and Son.

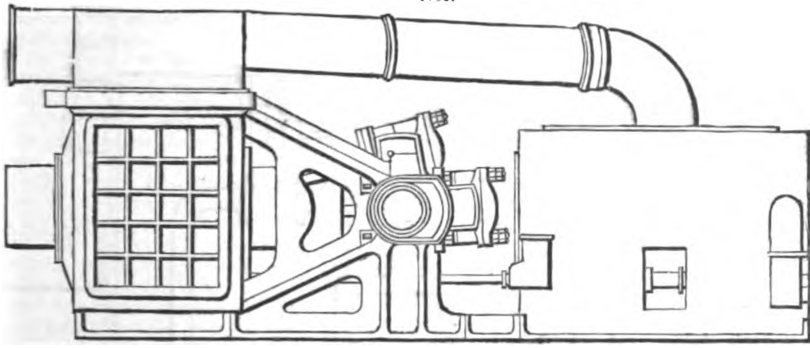
The cylinders are secured together on one side of the centre of the hull of the vessel. The trunks are double, that is, one trunk on each side of the piston passes direct through the front and back ends of the cylinders. The cross-head pin is connected by bolts and nuts passing through projections cast on the piston and front trunk, the back trunk being a separate casting, and secured by studs and nuts. The connecting rods are of the ordinary single-end kind, adjusted by securing bolts and nuts. The main frames are of cast iron, the caps of which are secured in a line with that of the cylinder. The cranks are counterbalanced by weights secured to the back of each, thus producing a uniform motion.

The slide-valve adopted by J. Penn and Son is the equilibrium double-ported. The friction is here greatly mitigated by a recess in the back of the valve, which encloses a ring and packing, the outer side of the ring bearing against the cover of the casing, and thus excludes the full area of the valve from being exposed to the action of the steam.

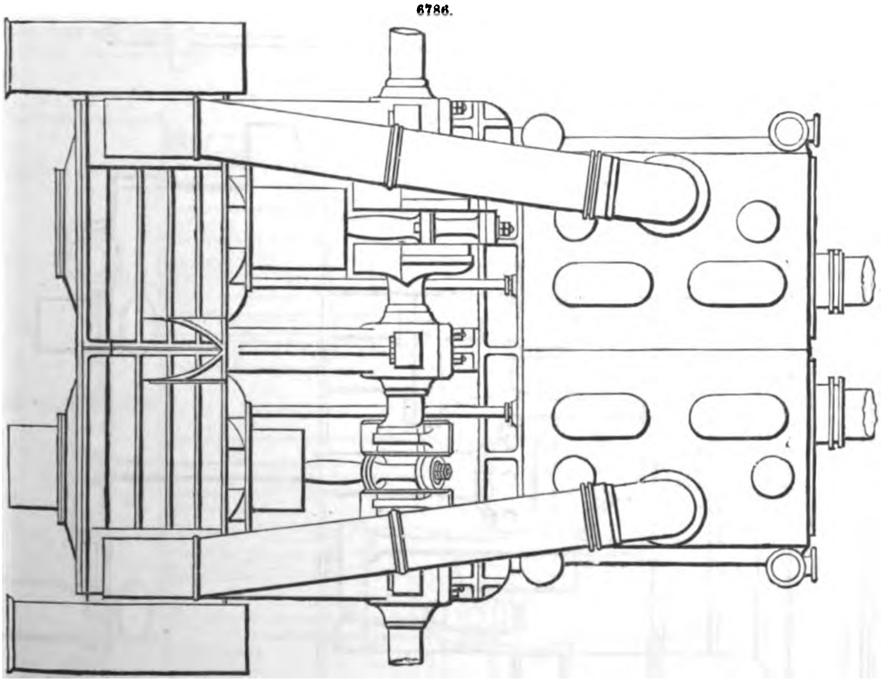
The mode of imparting the motion to the valve is by the ordinary slotted links and eccentrics. The valve-rod—when one is used—is guided beyond the casing by a guide-box secured to the main framing. When two rods are adopted, a cross-head connects them. The guides are above

and below the rods, the former being secured to the casing, thus dispensing with the guide connection with the main frame.

6785.



6786.



The mode of raising and lowering the link is generally by a rod connected to a lever keyed on a shaft; on this shaft is secured a quadrant gearing with a worm, the latter forming a portion of, or keyed on, the starting-wheel shaft. The connection of the lifting rod with the link is central, the firm seeming to prefer this to any other position.

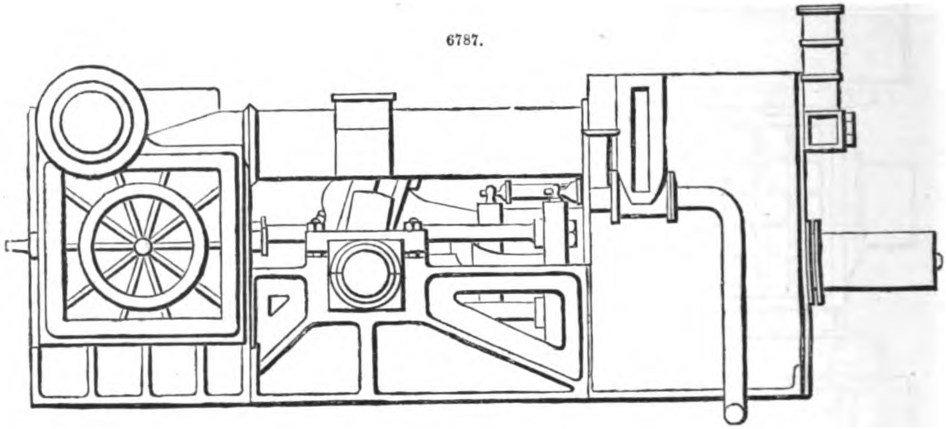
The mode of reversing is as follows;—Mitre-gearing on the wheel-shaft imparts motion to a rotatory box encompassing a perpendicular screwed rod, the lower end of the latter being connected to a lever counterbalanced at its outer extremity. A rod attached to this lever connects it with the link, and thus any motion imparted to the screwed rod is transmitted to the link.

The supply steam is admitted to the slide-valve casings through a separate bonnet or casing containing the expansion-valve. The exhaust steam passes through separate pipes leading from the cylinder to the condensers. The latter is so arranged that the condensing and discharge chambers for each engine are in separate castings, connected at the centre by bolts and nuts. The condensers are at the outer sides of this arrangement, or fore and aft of the hull; the discharge-chambers being placed in the middle. The suction and delivery valves are on the same level, above the barrels of the pumps. The feed and bilge pump barrels are cast with the condensing chambers. The valves are attached in suitable boxes, secured to the exterior of the chambers forming the sides. Motion to all the pumps is imparted by rods directly connected from the steam-pistons to the several pistons and plungers. The injection-valves are secured at the side of each condenser, opposite or beyond each exhaust steam pipe.

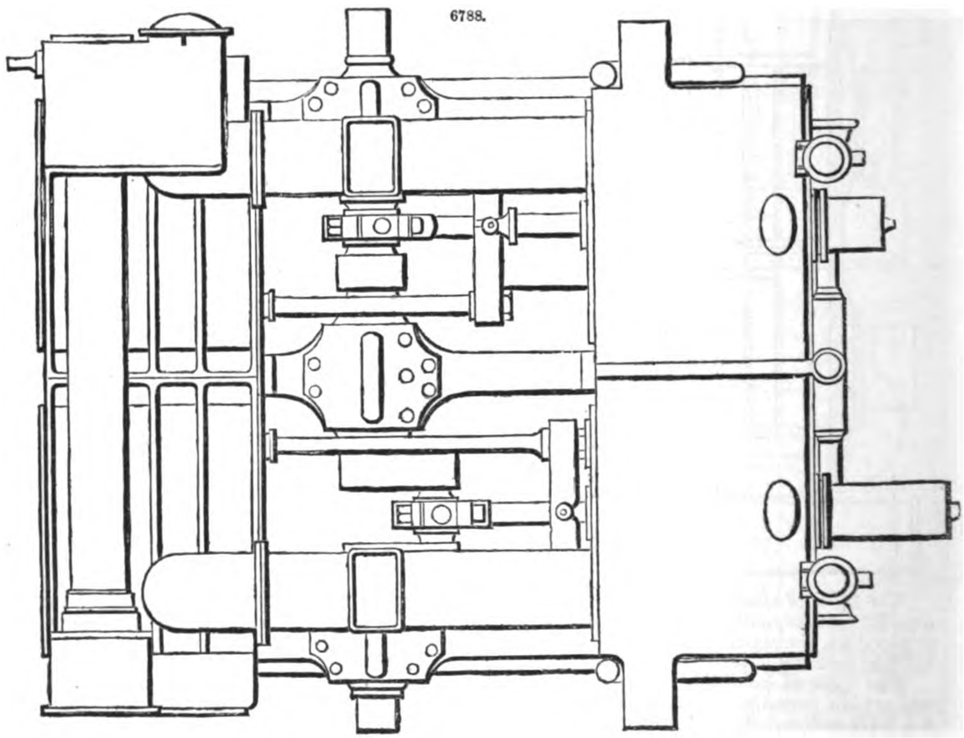
Return-acting Trunk-engines.—Figs. 6787, 6788, are of the return-acting trunk air-pump screw engine of R. Napier and Sons, Glasgow. The cylinders are attached together on the same side of

the crank-shaft, and the slide-valves are situated at the side of each cylinder fore and aft; the valve adopted being the equilibrium double-ported arrangement, packed at the back with the ordinary

6787.



6788.



ring, spring, adjusting studs and nuts. The centre of the valve-rod, unlike most examples by other makers, is above that of the crank-shaft. The motion—for the valve—is imparted by the ordinary slotted link, eccentric rods, and so on. The position of the link is at the side of the condensers. The gear for starting, stopping, and reversing is a screwed rod with a sliding block encompassing it, motion from the hand-wheel shaft being transmitted by mitre-gearing. The back portion of the sliding block—on the rod—is fitted into a guide secured to the side of the condenser, to prevent lateral disarrangement. There are two hand-wheels, one on each side of the condenser, keyed on the weigh-shaft, which latter is supported on the condenser passing across the top.

By this particular position of the starting gear a maximum length of eccentric rod is attained, while the cylinders are secured as near the crank-shaft as the length of the stroke of the piston will admit.

The injection-condensers are fitted with single-acting pumps, so arranged that the steam enters the condensing chamber at the front end from the top, and the chamber extends midway above the

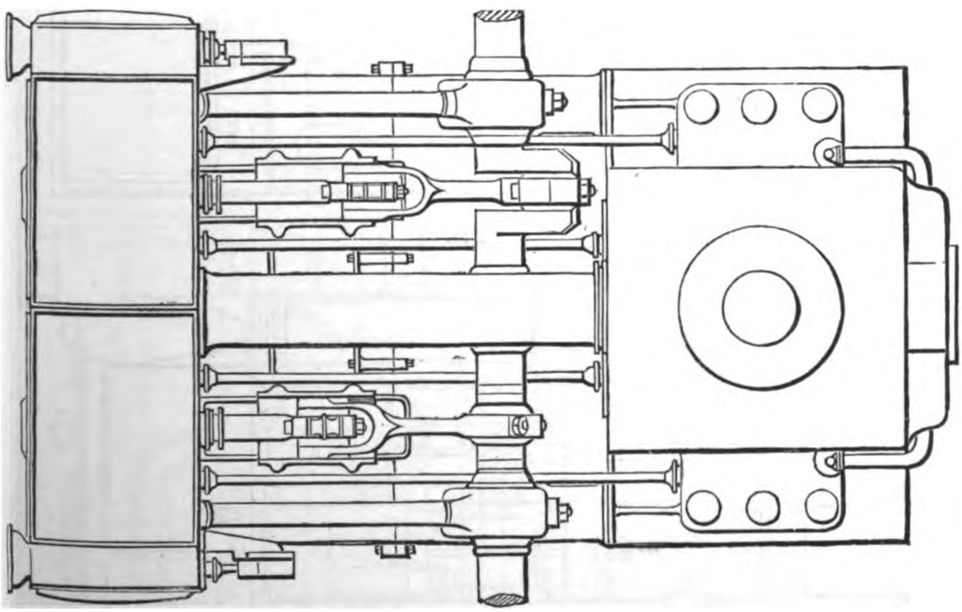
top of the pump. Channels are formed on each side of the air-pump barrel for the reception of the suction-valves, which are inverted to ensure a perfect drainage of the condensed steam. The discharge-valves are secured directly over those for the suction; and as the bottom of the discharge-chamber is on a level with the top of the pump-barrel, a thorough discharge of both *air* and water is effected, transversely for the entire width of the disposition. The injection-water falls through a perforated plate.

The plunger or trunk is a cylinder, closed at the back end, and the adjustment of the connecting rod is thus effected;—At the back, or within the end of the trunk, is secured a single eye fixed within a small cylinder, termed the adjusting tube, forming a portion of the trunk, projecting it a distance from, and equal to the length of the stroke of the engine. The securing end of the single eye is bored throughout its length to admit a rod, the end of which acts against the inside brass. Adjustment is attained by the outer end of the rod being connected to the extremity of the adjusting tube. The connecting rod is forked at the trunk end. The connection with the crank-pin is effected by securing bolts, brasses, and stop-pins of the ordinary kind.

The supply steam enters the top valve-casing secured on the slide-valve casing of the engine nearest the boiler. The expansion-valves are so situated to be instantaneously effective. The feed and bilge pumps derive their motion from the plunger or trunk of the air-pump; and their valves and boxes are at the back of the discharge-chamber, fitted with the suitable springs and adjustable connections. The shifting valves are secured at the back of each air-pump; underneath the latter is a passage from the condenser, by which a certain drain is secured. The injection-valves are at the side of each condenser, near the starting wheel, thus ensuring ready manipulation, without inconvenience; the cylinders are fitted with the necessary relief and blow-through valves; and lubricators are fixed at each end of the cylinder.

Single Piston-rod Engines, by Humphrys and Tennant, **Fig. 6789.**—The cylinders are here

6789.



secured together on one side of the crank-shaft, and have double-ported equilibrium slide-valves, packed at the back with a ring and gasket. The pistons are cast hollow, with ribs to retain the requisite strength while under pressure. The piston-rod is secured by a nut at the back of the piston. The stuffing box is the ordinary kind; the gland being adjusted by studs and nuts. The lubrication of the piston-rod is maintained by an oil cup, or channel, encompassing the rod beyond the packing gland, forming a part of the bush in the latter. In order to prevent the oil wasting by the motion of the piston-rod, a stuffing box and gland is placed beyond the oil-chamber, and thus economy of lubrication is ensured. The form of the piston-rod at the connection with the guide-block is similar to the letter ⊣ on its side.

The guide-block for the piston-rod is in halves, each portion being almost a duplicate of the other. At the under side of the block, below the piston-rod, flanges are cast; and underneath these is arranged a plain surface, termed the slipper or shoe. The line of contact of the slipper and the block is at an angle; thus it can always be adjusted by a stud and nut used for that purpose. The section of the guide-channel is of a double bracket, the under side being connected. The connecting rod is of a forked form clasping the sides of the block; the pin, forming the attachment, being situated in the centre of the block. The whole is adjusted by securing-bolts over and under the block-pin; the strains imposed on these bolts are, of course, equivalent to that exerted on and against the piston-rod, therefore the areas are equal. The nuts of the securing-bolts are prevented from coming loose by stop-rings, pins, and outside keys. The crank end of the connecting rod is

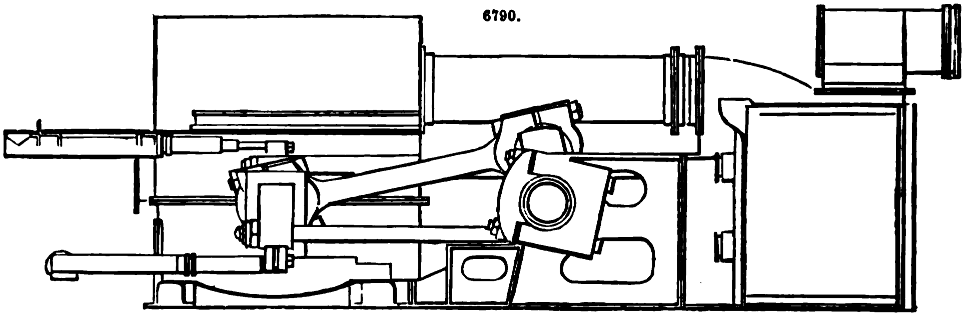
semi-solid, adjusted by securing-bolts, similar to those for the guide-block. The brasses are circular, retained by their contact with the securing-bolts, and thus angular seats are obviated. Suitable flanges prevent lateral movement, and lubrication is obtained by the wiper and suspended can, as for the guide-pin. The cranks and shaft are in one forging, of plain exterior, consistent with uniformity and strength.

The main frames next claim attention. The main frames are of cast iron, forming at the base, between the cylinders and crank-shaft, a floor that is connected to the condenser in the centre of each bearing.

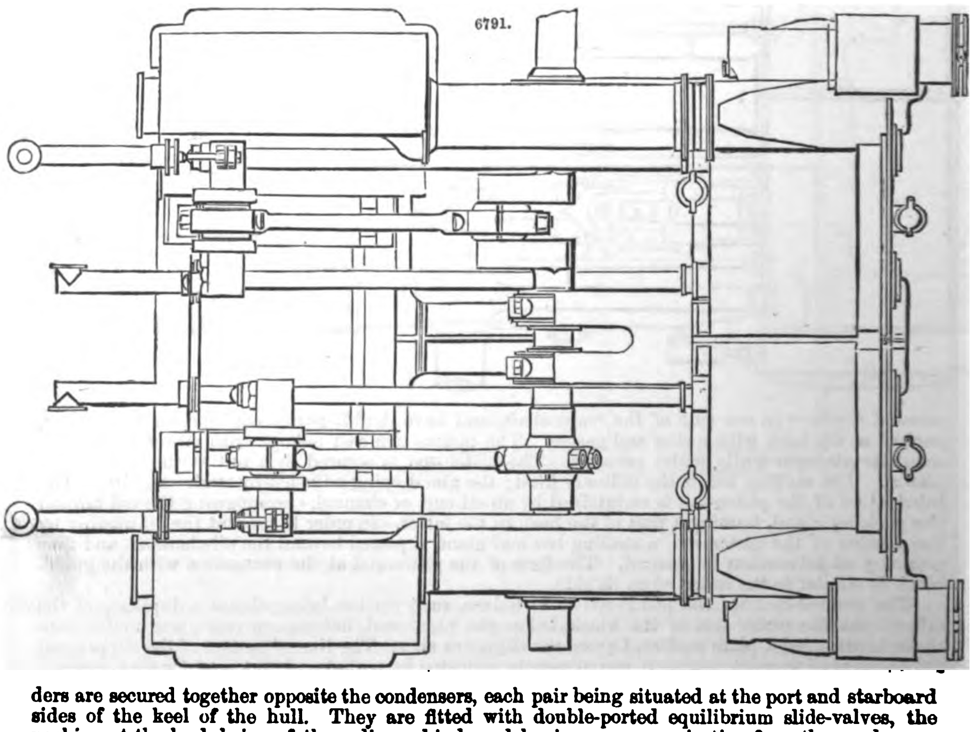
The guide-channel for the guide-block is secured by studs and nuts, being a separate casting. Between the guide-channel projection and the supports for the crank-shaft a transverse connection of the framing throughout is introduced, in order to ensure a perfect casting. The brasses in the main supports are the ordinary kind, adjusted with securing-bolts and nuts. It will be noticed that the frames between the cylinders and the crank-shaft supports are raised proportionately to the preceding examples, but very slightly from the base line, at the connections with the cylinders and the condensers. In order to resist the direct strain above the centre of the crank-shaft, a stay is secured between each frame to support the front of the cylinders, and by that connection the requisite resistance against the side strains is obtained. Each of the main bearings is provided with oil-chambers and water-tubes—the latter being required only in the case of heated bearings.

Return Connecting-rod Screw Engines, by Maudslay, Sons, and Field, Figs. 6790, 6791.—The cylin-

6790.



6791.

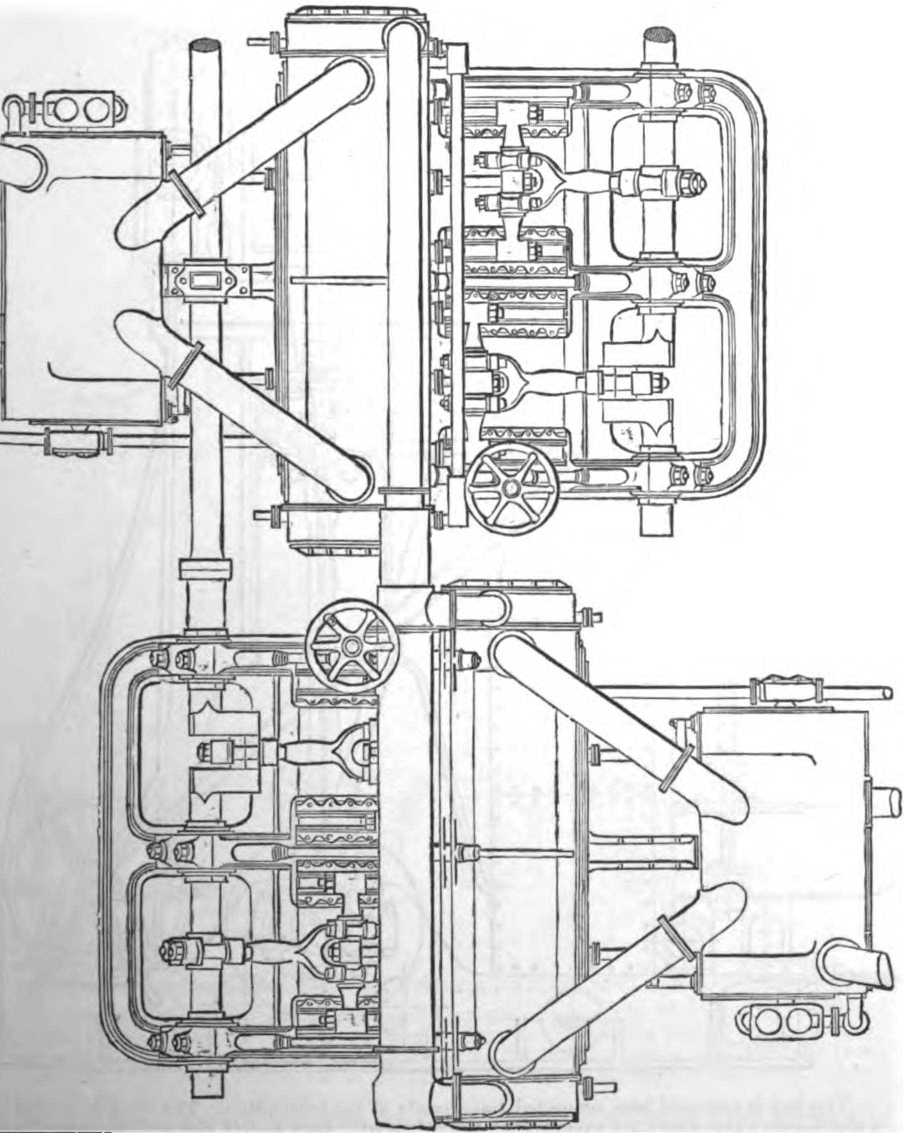


ders are secured together opposite the condensers, each pair being situated at the port and starboard sides of the keel of the hull. They are fitted with double-ported equilibrium slide-valves, the packing at the back being of the ordinary kind, and having a communication from the condenser, which assists to reduce the face friction. The supply steam enters the slide-casing through that for the expansion-valve, the latter casing being on the top of the former. Each casing is separately supplied with steam, so that an independent action is preserved.

In order to preserve a direct action from the eccentric, the slotted link is arranged to rest on the

block-pin when the link is lowered. With slide-valves of maximum area, two rods are introduced, each of which is fixed by nuts to a cross-head; and bracket bushes, secured to the main frame, form guides, through which the slide-rods pass. The link block-pin is secured to the cross-head at the back to retain a certain length of eccentric rod.

For raising and lowering the link, below the link, in the centre of the length of the main frames, is a weigh-shaft. On this is fixed a double lever, to which at one extremity is hung a counter-balance, and the other is connected to a vertical rod. This rod is attached at the upper end to a coarsely-pitched screwed rod, which passes through or fits in a bush supported in a standard, the latter being secured on the slide-valve casing. The bush forms part of a mitre-pinion, which gears with another pinion fixed on the hand-wheel shaft. On motion being imparted to the mitre-gearing, the double lever, by its connection with the screw, will be raised and lowered. The connection of the lever with the link is by a rod, the latter being attached to the centre of the length of the link at the one end, and to the lever by a slot and pin at the other. By this connection an almost equal action is imparted to the slide-valve, whether the link is raised or lowered. The position of the starting platform is between the condensers, each engine having separate starting gear.



6792.

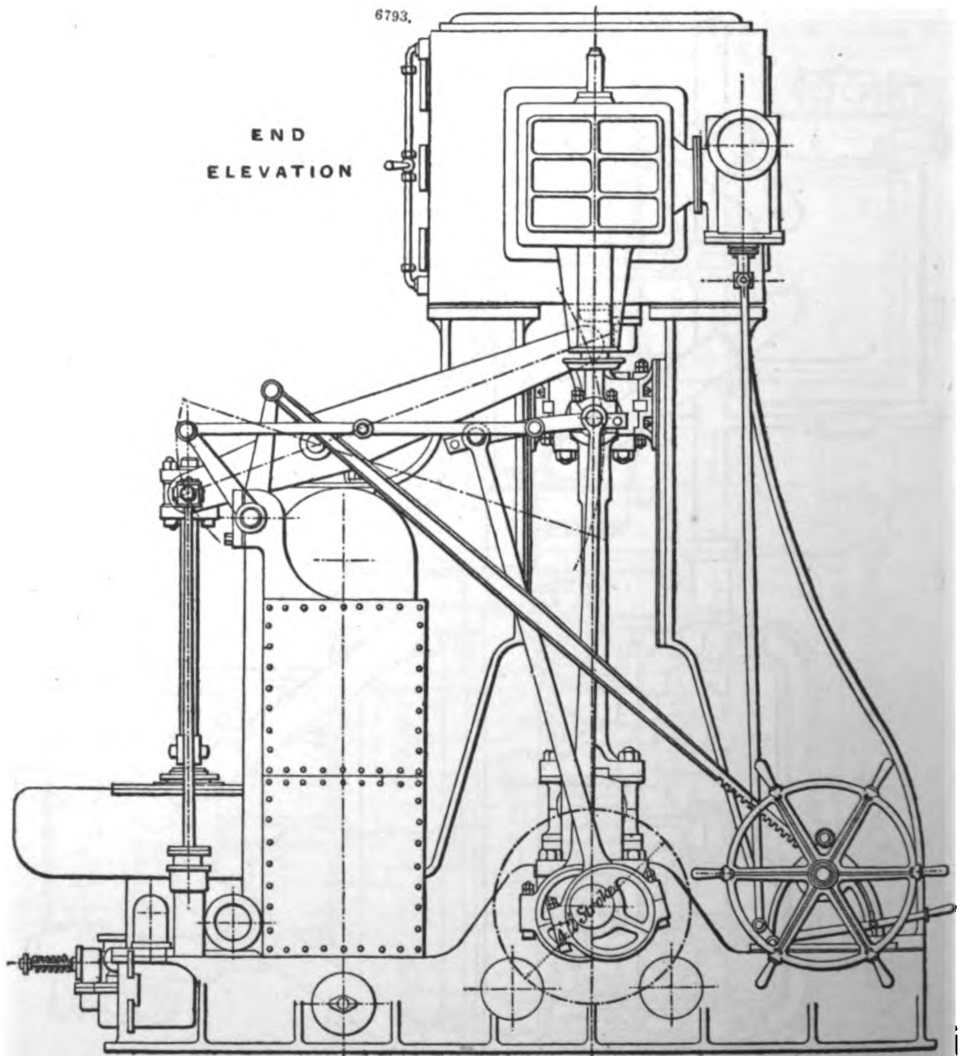
The hand-wheels are situated directly over the connecting rods, about midway of the length of the guide-channels; the other manipulating gear being close at hand.

The main brasses are fitted with caps, bolts, and nuts. It will be noticed that the centre frame has a double bearing, the central space being provided for the spur-wheel which imparts motion to the expansion-valves. The crank-shaft is in one forging; the connecting rods are singly connected

at each end with semi-solid heads and caps, adjusted by securing-bolts and nuts, and having suitable oil-cans and wipers for lubrication.

Fig. 6792 is the plan of an arrangement of single piston-rod direct-acting engines by J. and W. Dudgeon. Each arrangement is separate, without any connection of the working portions. The cylinders are the compound kind; the high pressure within the low. Three piston-rods are required for each engine, the centre rod being connected to the high-pressure piston. The guide-channels—below each piston-rod, connected to the annular piston—are the ordinary kind, arranged to receive slipper-blocks. The cross-head is secured to the piston-rod by nuts, and turned on each side of the central connection to receive the forked end of the connecting rod, which is of the T-end kind, with flat brasses, caps, and securing-bolts. The main frame, crank-shaft supports, and the connecting portions are in one casting, secured at the back and to the steam-cylinders. The brasses for the main bearings are adjusted, at an angle, by the ordinary securing-bolts and caps. The slide-valves are double-ported, to supply and exhaust the steam simultaneously from the respective cylinders, one valve only being requisite to each engine. The larger cylinder is double-ported on each side of the exhaust-port, and the passages, at the back and front end, communicate with the high-pressure cylinder.

6793.



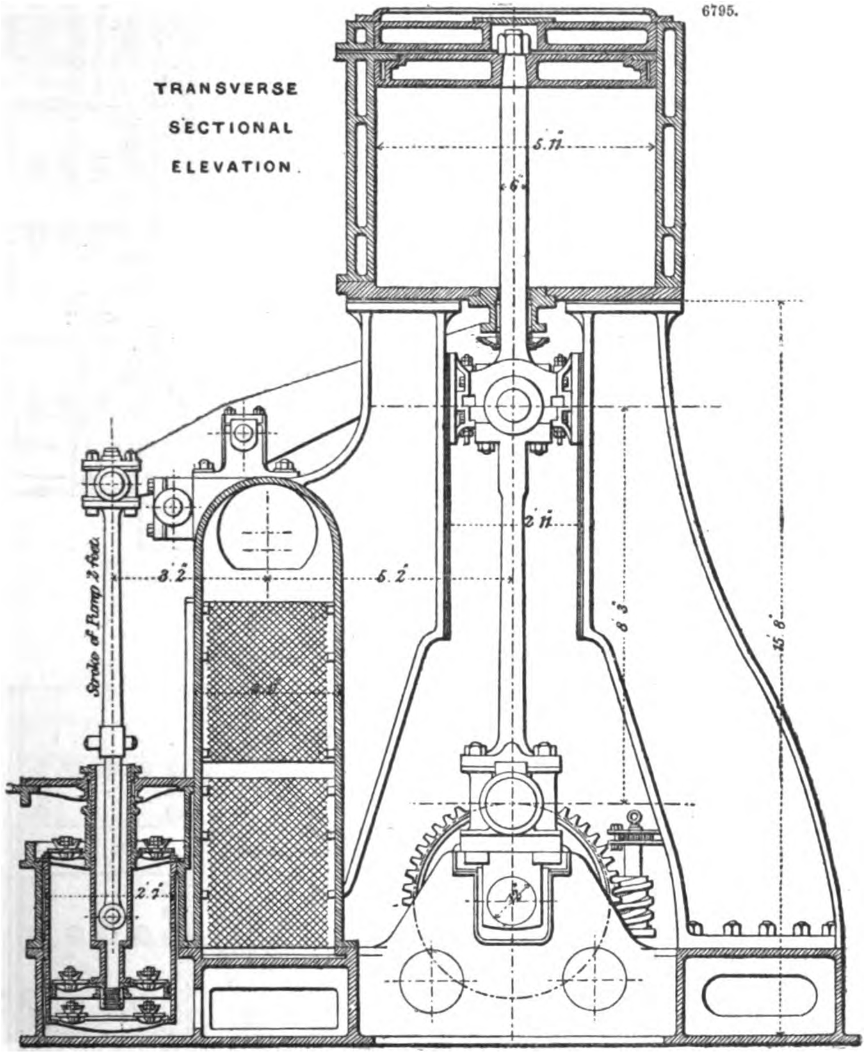
The link is two solid bars, connected transversely at the extremities. The block is inserted in a single eye, which forms the extremity of the valve-rod. Each bar of the link clasps the block, suitable recesses being formed for that purpose. The eccentric rods are connected to the outsides of each bar, and secured by separate pins. The lifting rod is connected, at the lower end, to the centre of the length of the link; the upper end being attached to a lever, whose shaft is supported in brackets, the latter being secured to the front of the cylinder. Motion is imparted to the lever

weight-shaft by a toothed quadrant keyed thereon. The hand-wheels are horizontally secured on vertical shafts; the latter are formed with worms, which gear with the quadrants. The wheels in question are situated at the inner extremities of each main framing. The starting platform, above the steam piping, supports the wheel-shaft columns, thus combining simplicity of connection with economy of construction.

The condensers, seen beyond the cylinders, Fig. 6792, at the back of the same, are the surface kind. The motion requisite for the air and circulating pumps, double acting, is derived from the steam-pistons. The exhaust steam enters the condenser at the top by separate pipes, connecting with the exhaust-passages on the cylinders. The supply steam pipe is placed almost in the centre of the entire arrangement, passing from end to end, and thus being common to each slide-casing.

The feed and bilge pumps are worked by arms secured on each air-pump rod. The valve-boxes are secured at the sides of each condenser, to facilitate access for inspection and repair.

6795.



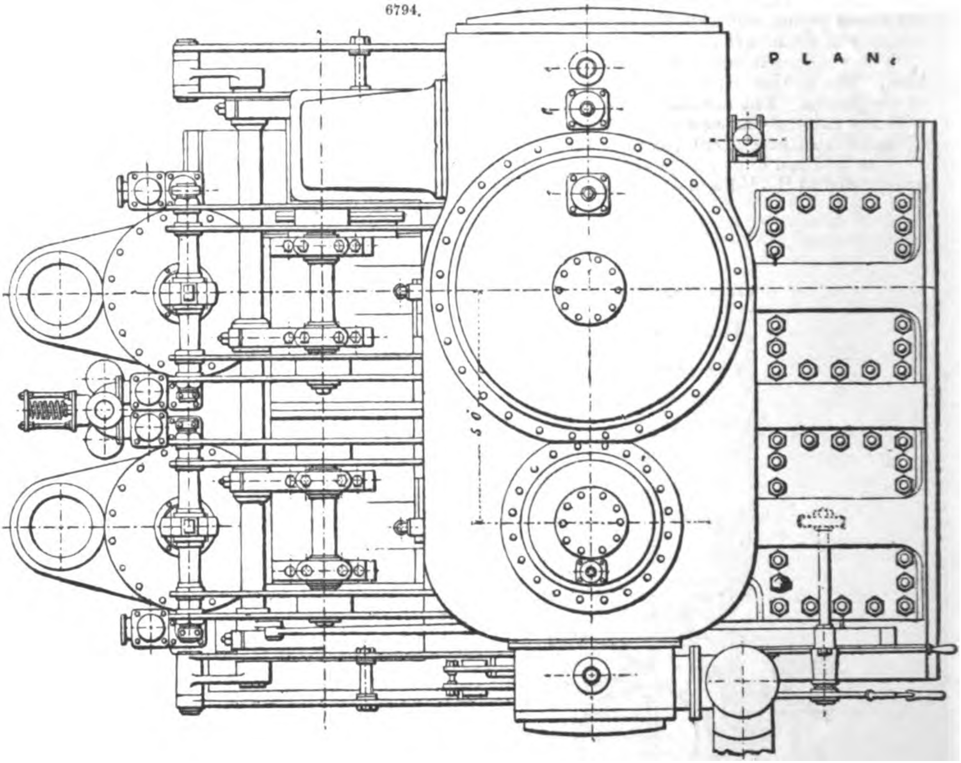
Figs. 6793 to 6798 are of a neat arrangement of compound engines by Day, Summers, and Co. Fig. 6793 is the end elevation, which shows the valve-handles and starting gear on the right hand of the crank-shaft, near the floor line, the gear being the rack-and-pinion type with the rack attached at an angle to the lever of the weight-shaft, on which are secured the two levers in connection with the links by the twin side rods.

The pump-motion gear is simple, being the general lever kind, with the usual link attachment to the main cross-head pin of the piston-rod. Above this is the high-pressure valve-casing, with the stop-valve casing at the right-hand side, and beyond that is the outline of the cylinder, with the indicator tubing shown on the left-hand side.

In the plan, Fig. 6794, is seen the receiver connecting the high and low cylinders on both sides; there is, however, not much detail to direct attention to, because the two views correspond.

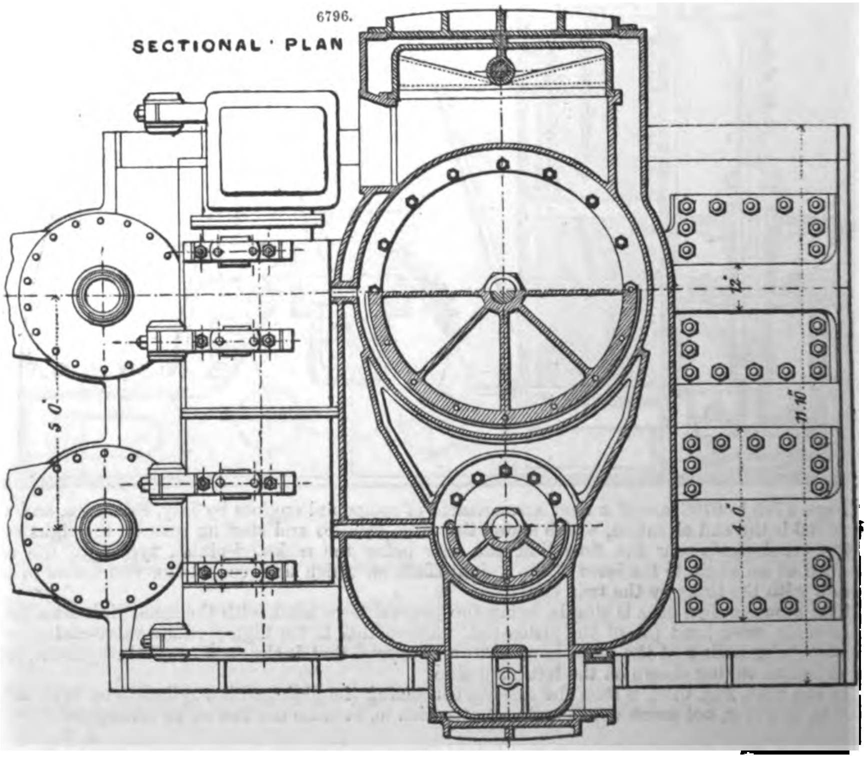
Fig. 6795 is a transverse sectional elevation, which shows sections of the low-pressure cylinder, surface condenser, and air-pump. The cross-head guide-block of the main steam piston-rod is

6794.



6796.

SECTIONAL · PLAN



novel in design and arrangement, consisting of a block formed with the rod, and a cap on the lower half, secured by bolts and nuts that also adjust the wearing surfaces around the cross-head pin; the lateral adjustment of the working surfaces at the sides is attained by screw wedges with nuts at each end.

6797.

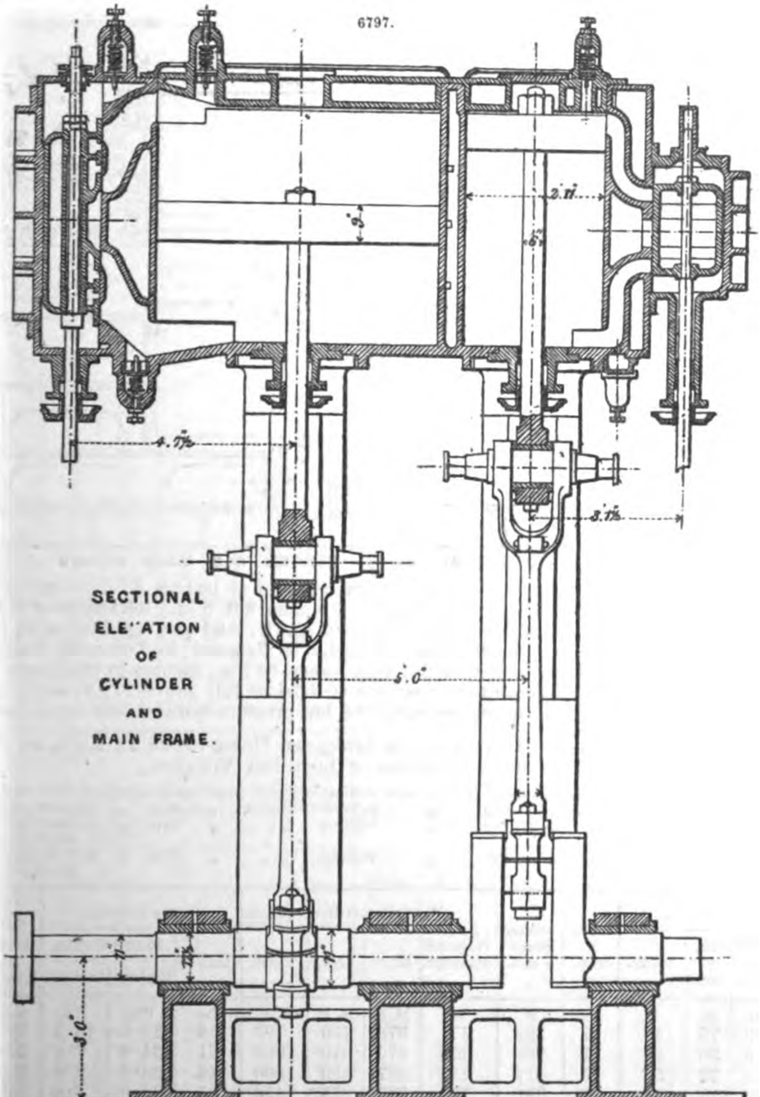
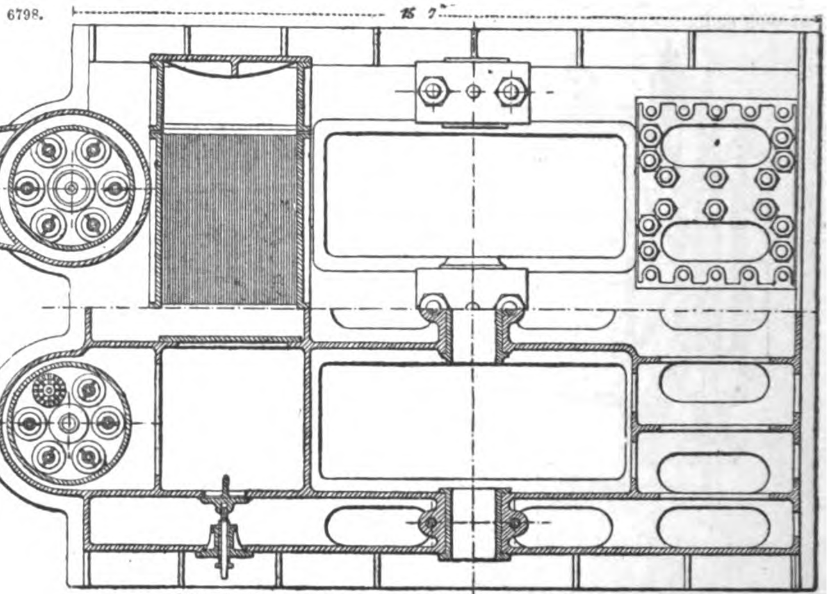


Fig. 6796 is the sectional plan of the cylinders, slide-valves, casings, and pistons, showing the receiver that connects the high-pressure and low-pressure cylinders; and on the left-hand side are the condenser-pumps and brackets, opposite to which is the foundation framing, on which the guide-frames are supported. The slide-valve of the high-pressure cylinder, Fig. 6797, is single-ported, with no extra cut-off valve at the back, the grade of expansion being attained by shifting the link-motion. The slide-valve of the low-pressure is double-ported, or equilibrium double-ported. The cross-heads are shown complete with the block-head in section, as also are the cranked shaft bearings and the lower frame bearers. Fig. 6798 is the sectional plan of the condenser and main frame; the air and circulating pumps are also in section, to show the number of the piston-valves in the one case and the discharge-valves in the other. The sections of the main frame and condenser clearly explain its form and the necessary ribs to obtain the requisite strength.

The following are the dimensions of these engines, which are of 300 horse-power, and were built for the Royal Mail Company's screw steamer Liffey;—Nominal horse-power collective, 300; diameter of high-pressure cylinder, 36 in.; diameter of low-pressure cylinder, 72 in.; length of stroke, 4 ft. 2 in.; diameter of air and circulating pumps, 30 in.; diameter of feed and bilge pumps,

5 in.; number of tubes in each condenser, 2064; length of tubes in each condenser, 7 ft. 6 in.; condensing surface in each condenser, 3040; diameter of propeller, 15 ft.; number of blades in

6798.



SECTIONAL PLAN OF CONDENSER AND MAIN FRAME.

each propeller, 4; pitch of propeller, 19 ft. uniform; number of boilers, 4; diameter of boilers, oval, 14 ft. 3½ in. high × 10 ft. 2½ in. wide; length of boilers, 8 ft. 5 in.; total number of tubes in all boilers, 864; total heating surface in all boilers, 5005 sq. ft.; total number of furnaces, 12; area of total number of furnaces, 186·7 sq. ft.; size of funnel, 6 ft. diameter; load on safety-valve, 60 lbs. the square inch; pressure in boilers on at full trial power, 60 lbs.; vacuum in condenser on trial at full power, 26 in.; average revolutions a minute on trial at full power, 71; average indicated horse-power, both engines, high-pressure cylinder 754, low-pressure cylinder 806—total, 1560.

TABLE I.—AVERAGE CONSUMPTION OF COAL, TO EACH INDICATED HORSE-POWER AN HOUR, BY STEAM SHIPS WITH COMPOUND ENGINES IN LONG SEA VOYAGES.

Class A Compound Engines with one High and one Low pressure vertical Cylinder, working two cranks at right angles.
„ B „ „ two „ two „ inclined Cylinders, „ two „ opposite each other.
„ C „ „ two „ two „ vertical „ „ two „ at right angles, cylinders combined, annular.
„ E „ „ two „ two „ vertical „ „ two „ at right angles, cylinders combined, high at top.

Engines.		Cylinders.			Revs. a min.	Piston Speed a min.	Screw Propeller diameter.	Indicated Horse-power.			Steam Pressure.			Coal Consumption.	
No.	Class.	Diameter. High.	Diameter. Low.	Stroke.				High.	Low.	Total.	Boiler.	Mean Effective. High cyl	Mean Effective. Low cyl.	Every 24 hours.	Each Ind. H. P. an hour.
		in.	in.	in.	No.	ft.	ft.	H. P.	H. P.	H. P.	lbs.	lbs.	lbs.	tons.	lbs.
1	A	42	75	42	47	329	17	373	420	793	58	27·0	10·3	24·5	2·80
2	A	45	80	36	51	306	15½	476	349	825	51	34·2	7·5	23·0	2·60
3	A	36	72	50	50	417	14¾	467	393	860	46	36·4	7·6	24·0	2·60
4	A	62	112	48	47½	381	18	787	665	1452	45	22·6	5·8	33·8	2·18
5	A	38	68	33	61	335	12	298	311	609	45	25·8	8·4	13·8	2·12
6	C	22	52	36	55	330	14	292	204	496	48	38·6	6·5	11·2	2·12
7	A	34	59	36	58	348	16	304	336	640	55	35·8	10·5	14·5	2·11
8	A	51	86	48	54	434	18	723	766	1489	49	26·9	10·0	33·2	2·08
9	A	46	80	39	65	422	14	527	710	1237	54	24·8	11·0	27·6	2·08
10	A	60	104	48	60	480	18	1027	1493	2520	52	25·0	12·1	55·8	2·07
11	A	41	70	39	70	455	15	361	525	886	58	20·8	9·6	19·5	2·05
12	A	46	82	48	54	432	17	761	633	1394	54	35·0	9·1	30·0	2·01
13	A	48½	84½	42	61	427	16	669	700	1369	55	28·0	9·6	30·0	2·00
14	A	34½	60	36	53	316	15	222	226	448	54	15·0	8·4	9·6	2·00
15	A	46	80	39	..	..	14¼	..	..	..	50	..	..	19·4	1·99
16	A	36	72	50	52	433	14¾	457	401	858	54	34·2	7·5	18·4	1·95
17	A	26	52	36	51	306	17	153	211	364	53	31·0	10·7	7·6	1·94
18	A	44	78	42	57	399	15¼	456	508	964	60	24·8	8·7	16·5	1·70
19	B	38	76	51	25¼	216	Paddle	553	432	985	55	37·3	7·3	18·0	1·70

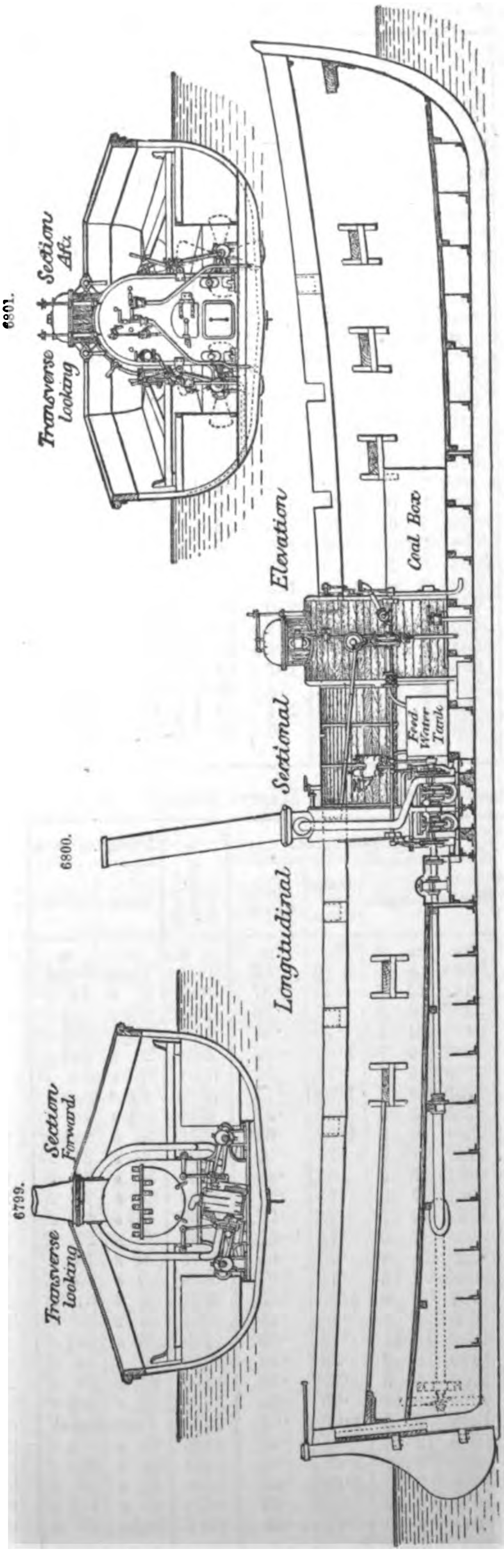
Average Consumption of Coal, lbs. each Ind. H. P. an hour, 2·11

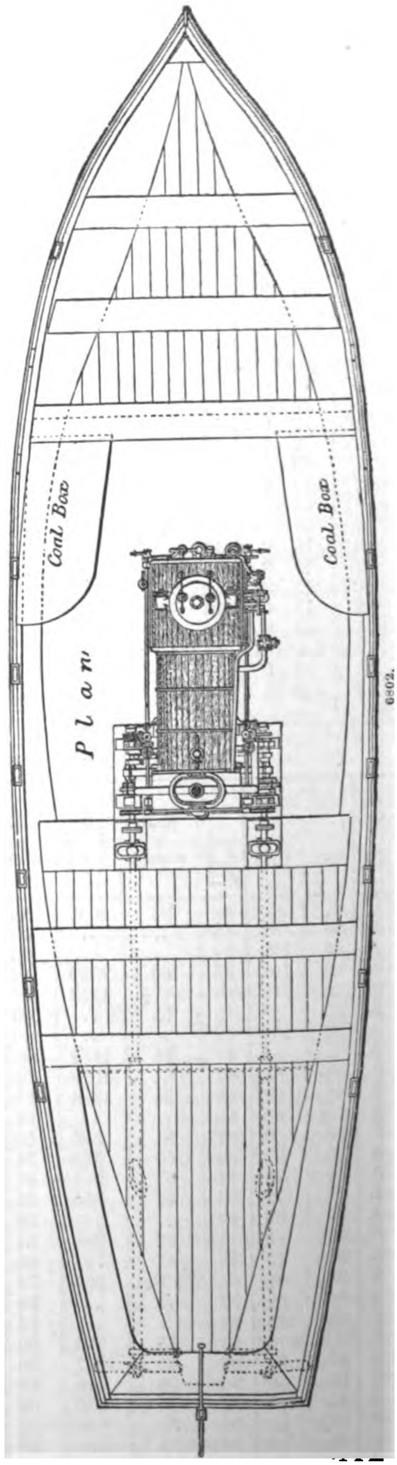
TABLE II.—BOILERS OF COMPOUND MARINE ENGINES.

Engine No.	No. of Boilers	Boiler Shell. Diameter.		Boiler Shell. Length.		Boiler Shell. Thickness.	Furnace Flues. Total No.	Furnace Flues. Diameter.		Tubes. Total No.	Tubes. Length.		Tubes. Diam. external.	Fire-grate Area total.	Steam Pressure working.	Total Heating Surface. Tubes.	Total Heating Surface. Furnaces, &c.	Total Heating Surface. Total.
	No.	ft.	in.	ft.	in.	in.	No.	ft.	in.	No.	ft.	in.	in.	sq. ft.	lbs.	sq. ft.	sq. ft.	sq. ft.
20	6	14	3	10	4	·87	18	3	6	1260	7	5	3·50	315	60	8615	1986	**10,601**
21	6	10	8	17	0	·87	24	3	0	1392	6	9	3·50	432	65	8602	1536	**10,138**
10	3	12	3	16	0	·78	18	3	0	960	6	9	3·75	297	56	6355	1325	**7,680**
4	8	12	0	8	0	·75	24	3	1	1392	5	6	2·75	333	50	5510	1745	**7,255**
22	3	11	5	17	0	·75	18	2	10	1110	6	6	3·00	306	60	5661	1422	**7,083**
23	3	12	3	16	0	·81	18	3	1	924	6	9	3·75	279	60	6122	856	**6,978**
8	2	13	4	18	8	·81	12	3	3	840	7	6	3·62	228	60	5959	968	**6,927**
13	2	13	3	18	0	·87	12	3	3	868	6	6	3·50	234	55	5060	1150	**6,210**
12	2	12	7	17	1	·75	12	3	0	868	7	0	3·25	216	60	5164	902	**6,066**
24	4	12	0	8	11	·75	12	3	0	876	6	0	3·00	180	60	4042	1026	**5,068**
2	4	10 × 13½ ft.		9	5	·62	12	2	10	600	7	0	3·50	187	52	3850	1158	**5,008**
3	4	10 × 13½ ft.		9	5	·62	12	2	10	600	7	0	3·50	187	54	3850	1158	**5,008**
18	2	10	6	17	6	·69	8	3	3	816	6	4	3·00	182	60	4000	720	**4,720**
16	2	12	3	17	6	·75	8	3	6	552	7	6	3·75	168	55	4067	575	**4,642**
25	2	12	0	16	5	·75	12	2	10	576	7	0	3·50	170	60	3132	1191	**4,323**
26	2	12	3	17	6	·75	12	3	1	480	7	6	3·75	185	54	3534	763	**4,297**
1	2	13	1	10	7	·87	8	2	10	456	8	0	3·50	136	60	3342	726	**4,068**
19	2	12	0	16	6	·75	12	3	0	472	7	0	3·75	180	55	3243	761	**4,004**
15	2	12	0	12	0	·75	12	3	0	904	5	0	2·62	189	50	3104	526	**3,630**
27	2	10	10	12	8	·75	8	3	1	768	5	2	3·00	120	64	3078	460	**3,538**
28	2	10	6	15	0	·75	8	3	1	640	6	0	3·00	135	60	3014	475	**3,489**
9	2	11	9	12	6	·75	12	2	10	816	5	0	2·62	170	56	2799	623	**3,422**
7	2	14	3	9	3	·87	6	3	6	420	6	3	3·75	115	60	2557	603	**3,160**
11	2	11	0	13	6	·75	8	3	0	568	5	6	3·25	114	60	2607	491	**3,098**
14	1	13	6	15	9	·87	6	3	2	396	6	4	3·50	107	60	2268	427	**2,695**
6	2	9 × 14 ft.		9	2	·56	4	3	3	324	6	6	3·50	76	65	1790	502	**2,292**
5	1	12	0	12	0	·75	6	3	1	506	5	0	2·62	104	48	1738	289	**2,027**
17	2	9	10	10	1	·62	4	2	11	268	7	3	3·25	66	50	1677	305	**1,982**

TABLE III.—SURFACE CONDENSERS OF COMPOUND MARINE ENGINES.

Engines. No.	Engines. Class.	Cyls. Diam. High.	Cyls. Diam. Low.	Stroke Length.	Revs. a minute.	Indicated Horse-power working.	Steam Pressure working.	Condenser Tubes. Number.	Condenser Tubes. Length.		Condenser Tubes. Diam. external.	Condenser Tubes. Space between.	Total Condensing Surface.	Circulating Pump. Diam.	Circulating Pump. Stroke.	Condenser vacuum working.
		in.	in.	in.	No.	H. P.	lbs.	No.	ft.	in.	in.	in.	sq. ft.	in.	in.	Ins. Mer.
20	A	56	97	48	..	..	60	2000	8	6	1·00	·75	4459	Centrifugal		25½
21	A	60	106	54	..	..	65	2419	15	6	·75	·37	7361	17 D	24 *D*	27½
10	A	60	104	48	60	2520	56	2257	14	1	·75	·35	6249	13½ D	26½ *D*	27¾
4	A	62	112	48	47½	1452	50	2415	14	1	·75	·35	6666	13½ D	32½ *D*	28
22	A	50	88	45	53	..	60	1706	6	7	1·00	·62	2934	26 S	22½ *S*	25
23	A	60	104	48	..	..	60	2256	14	0	·75	·35	6201	16 D	24 *D*	28½
8	A	51	86	48	54	1489	60	1759	8	6	1·00	·75	3914	Centrifugal		26½
13	A	48½	84½	42	61	1369	55	1725	13	4	·75	·37	4504	19½ S	16 *D*	28
12	A	46	82	48	54	1394	60	2304	6	9	1·00	·62	4078	26 S	25½ *S*	25
24	A	49½	86	45	..	..	90	1740	11	6	·75	·35	3929	20 S	21 *D*	27¾
2	A	45	80	36	51	825	52	4872	5	6	·56	·44	3944	36 S	24 *S*	26
3	A	36	72	50	50	869	54	2064	7	6	·75	·37	3040	30 S	25 *S*	26
18	A	44	78	42	57	964	60	1338	12	7	·75	·37	3250	18½ S	15 *D*	29
16	A	36	72	50	52	858	55	2064	7	6	·75	·37	3040	30 S	25 *S*	27
25	A	46	82	42	..	..	60	1228	11	6	·75	·35	3773	20 S	18 *D*	27
26	A	36	72	40	52	780	54	2064	7	6	·75	·37	3040	30 S	25 *S*	27
1	A	42	75	42	47	793	60	1797	6	0	1·00	·62	2821	26 S	21 *S*	26
19	B	38	76	51	25½ Pad.	985	55	1663	8	3	·75	·35	2694	16 D	20 *D*	27½
15	A	46	80	39	..	..	50	1292	10	10	·75	·35	2758	16 S	20½ *D*	28
27	A	39½	68	42	..	..	64	1170	9	9	·75	·35	2240	20 S	16 *D*	27
28	E	26 26	52 52	42	45	820	60	1900	6	3	·75	·50	2400	24 S	23 *S*	26½
9	A	46	80	39	65	1237	56	1289	10	10	·75	·35	2752	16 S	20½ *D*	27½
7	A	34	59	36	58	640	60	1342	7	2	1·00	·75	2573	Centrifugal		28
11	A	41	70	39	70	886	60	898	12	5	·75	·35	2189	14 S	17¼ *S*	27
14	A	34½	60	36	53	448	60	890	7	9	1·00	·75	1811	21 S	36 *S*	27
6	C	22	52	36	55	496	65	608	7	10	1·00	·87	1246	22 S	18 *S*	26½
5	A	38	68	33	61	609	48	911	9	2	·75	·35	1654	13 S	15¾ *D*	28½
17	A	26	52	36	51	364	50	914	6	0	·75	·31	1112	20½ S	19 *S*	27

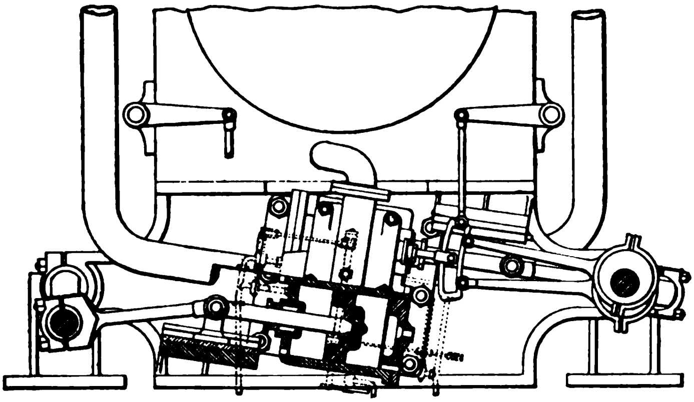

6801.
Transverse Section looking Aft.
6800.
Longitudinal Sectional Elevation
Coal Box
Feed Water Tank
6799.
Transverse Section looking Forward


6802.
Plan
Coal Box
Coal Box

Tables I., II., and III., giving various particulars relating to compound engines, are taken from a most interesting paper read by Fredk. J. Bramwell, before the Inst. Mechanical Engineers in 1872. In Table III., under column "Circulating Pump," Diameter—s denotes single pump, D, double pump; Stroke—*S*, single acting, *D*, double acting.

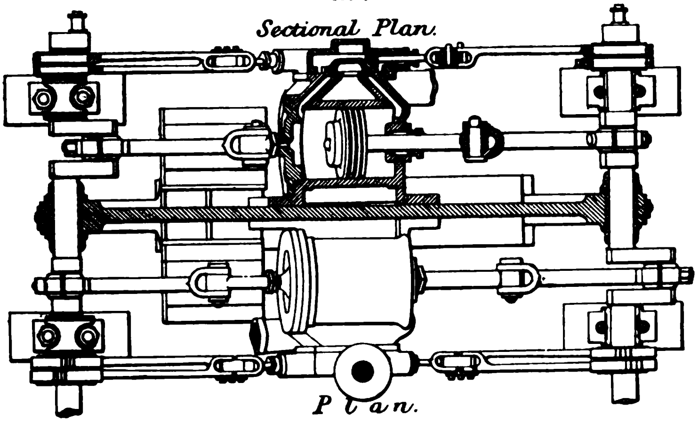
6803.

Front Elevation.



6804.

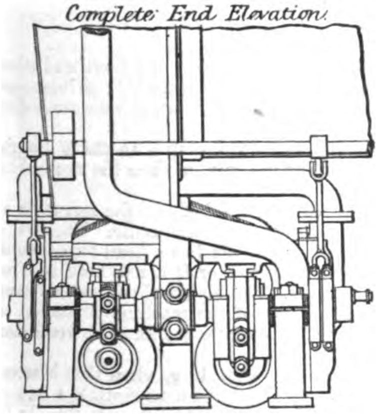
Sectional Plan.



Plan.

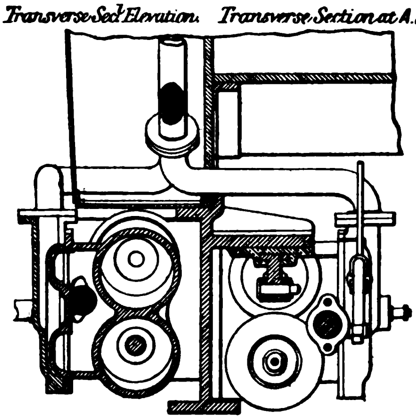
6805.

Complete End Elevation.



6806.

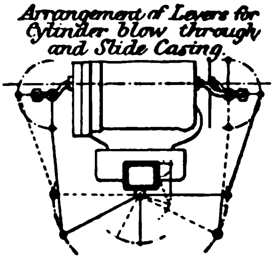
Transverse Sec. Elevation. Transverse Section at A.B.



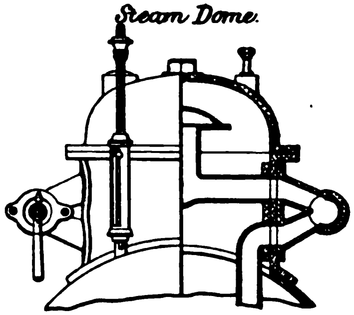
Steam-Launch Screw Engines.—Steam launches are used in place of the twelve or sixteen oared boats that were formerly employed as tenders to men-of-war. The row-boats were propelled at the rate of about 7 miles an hour, but the steam launch runs 12 miles an hour with ease. The boilers

used with steam launches are usually of the locomotive class, and the engines vertical, either secured to the shell at the fire-box end or to the smoke-box. N. P. Burgh having to design launch engines for Maltese service, has ignored the usual arrangements, and placed the engines at an angle *under* the smoke-box, thus making the support for that box the securing plate for the engines. The illustrations, Figs. 6799 to 6809, show a side elevation of Burgh's engines, sections and complete views. The arrangement consists of four cylinders, each pair being in one casting, and secured to the box support plate, as in plan Fig. 6804. Fig. 6805 is the end elevation, and Fig. 6806 shows sections through one cylinder, and also through the slipper guide bracket. Fig. 6807 is a skeleton arrangement of the lever-gear for the blow-through cocks, showing that one hand manipulates the entire set. One of the improvements Burgh introduced was placing the supply steam pipes inside the boiler, and forming the steam-cocks with double branches for that purpose, as shown in section and complete views by Figs. 6808, 6810; after the pipes passed through the boiler they were

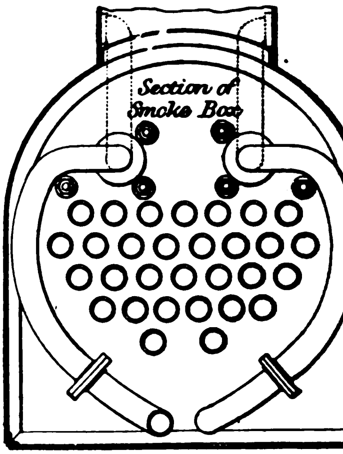
6807.

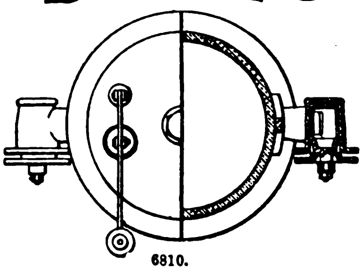


6808.



6809.





6810.

curved down on each side of the flame-tubes in the smoke-box, Fig. 6809. To make this arrangement fully understood we have illustrated its application in a launch, as shown in four views, Figs. 6799 to 6802.

See Marine Engine. Stationary Engine.

SCREW-MAKING MACHINE.

Figs. 6811 to 6815 refer to a machine for turning and nicking the heads of joiners' and other wood screws. The machine has been brought to its present form through a number of ingenious combinations, but the most important feature about it, the feeding arrangement, and the method of driving and stopping the spindle, is the invention of Wm. Avery.

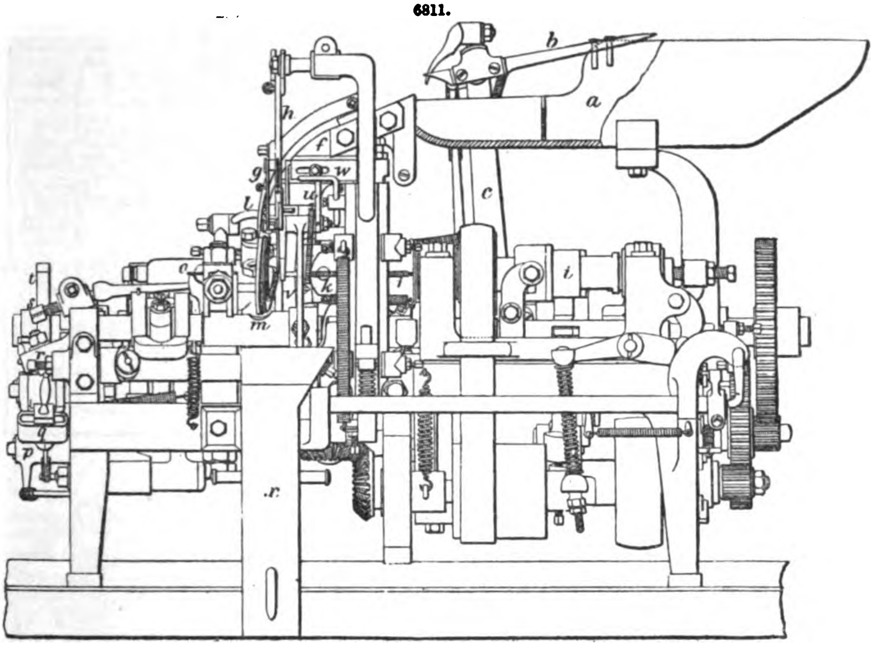
Fig. 6811 is a front elevation; Fig. 6812, back elevation; Fig. 6813, plan with the V trough for holding the hopper or rough screw-blanks, drawn in dotted outline only, to show the mechanism below more clearly. Figs. 6814, 6815, end elevations.

The screw-blanks are formed from wire of the size required for the body of the screws, in a heading machine, into which the wire is fed by an intermittent motion through a die. The wire is then cut off to the required length, and the short length held in the die has a head formed on it by the wire being pressed into a conical recess in the die by a plunger; or if a rose head is to be formed, the recess of corresponding shape is formed in the plunger. The blanks thus produced have burrs and irregularities on the heads, which it is one of the objects of the machine illustrated to remove by a turning process. The formation of the nick across the head for the screw-driver is also effected in the same machine.

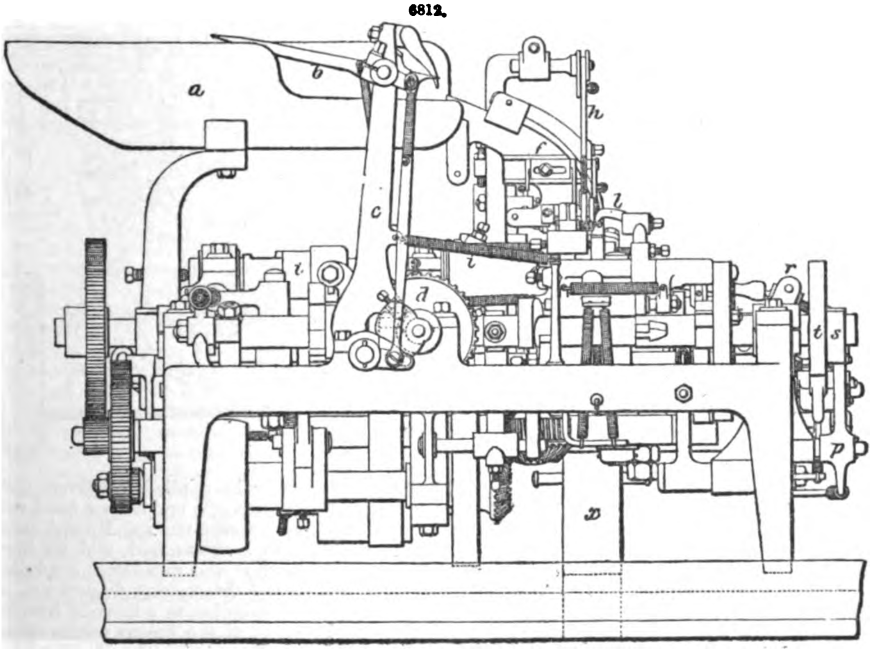
The screw-blanks are taken from the heading machine, and after annealing, when that is necessary, are thrown loosely into the hopper or trough *a*. The machine being set in motion, a fork or picker-up *b* is caused by the frame *c*, operated by the cams *d*, *e*, to vibrate forward and dip its points down into the irregular mass of screw-blanks in the hopper, tilting up as it goes back, as in Figs. 6811, 6812, certain of the screw-blanks being caught with their stems between the blades of the fork and suspended by their heads. The fork *b* is then brought back so that its hinder part comes in line with a pair of curved cheeks *f*, forming a kind of railway down which the blanks slide

from the fork, which, it will be seen, is thus the feeding instrument. It is arranged to act once only for every two or three screw-blanks turned and nicked, as it generally picks up several blanks at each movement. As the blanks are sliding down the curved railway f, the lowermost blank drops in a horizontal position between the jaws of a pair of yielding nippers g, and is there held until required. It is then seized by another pair of nippers h and moved downwards, still being held

6811.



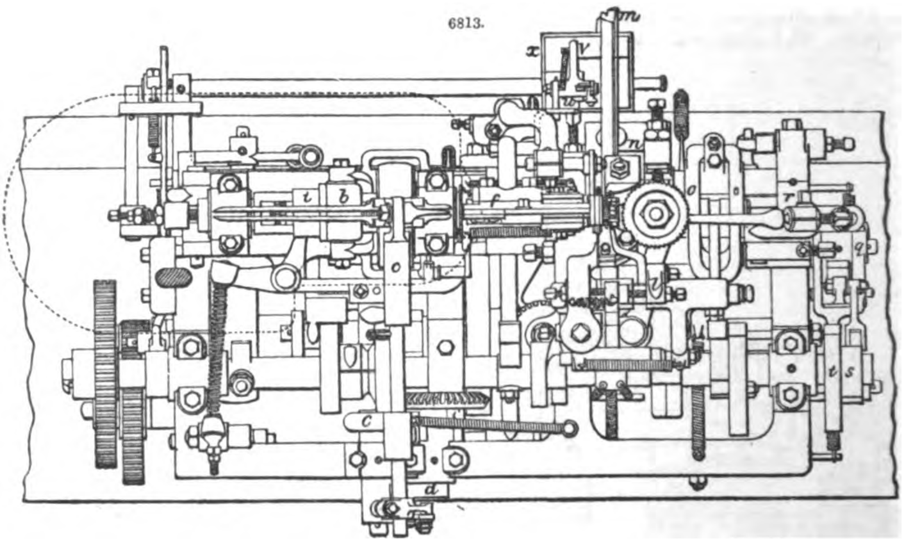
6812.



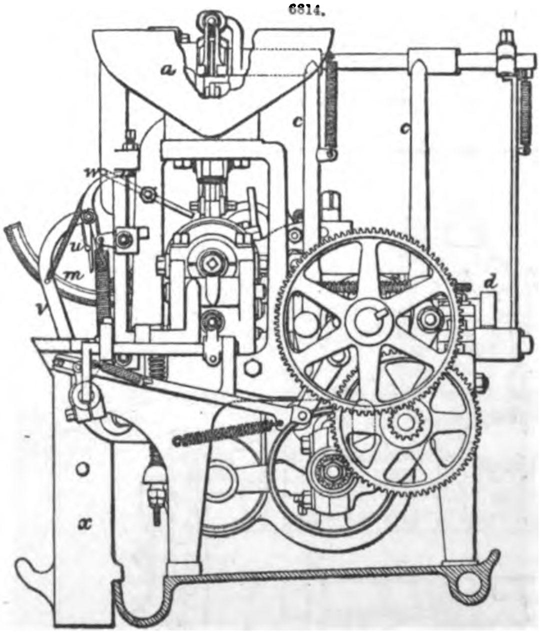
horizontally, out of the grip of the first-named nippers g, and brought opposite to the end of a revolving spindle i, furnished with holding-jaws or chucks k. The spindle i being stopped for an instant, and the jaws having been opened to liberate the blank last finished, the plain end of the new blank is thrust by a finger l into the jaws, which then close, the nippers h retire, and the spindle and blank are set revolving; a back-stay is brought up to support and steady the blank

and cutter *m*. This cutter is fixed into the oscillating tool-rest *n*, and is shaped to suit the head to be turned. It is applied gradually, and the head roughly turned, after which the cutter *m* is with-

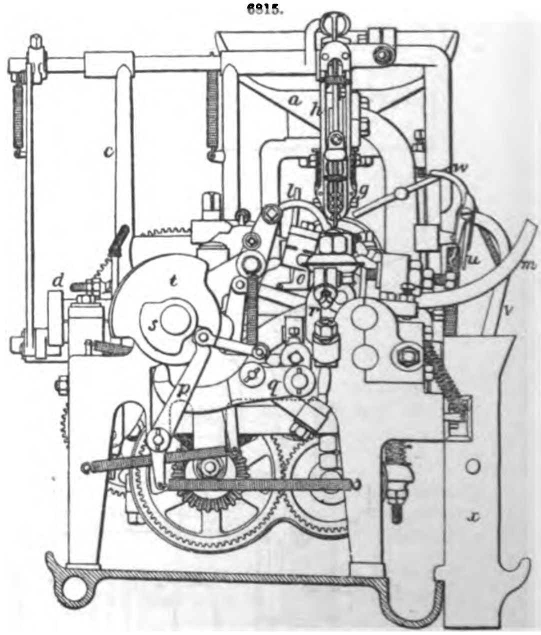
6813.



6814.



6815.



drawn, the spindle *i*, with its partly-turned blank, stopped, and a brake applied to prevent their revolving, while the revolving saw *o* is brought forward by the levers *p*, *q*, *r*, and cams *s*, *t*, and cuts the nick in the head of the blank. When this is done, the saw retreats, the spindle and blank revolve again, the cutter *m* is brought up a second time, but with a slower feed, and the burrs left by the nicking saw are removed, and the head generally smoothed and finished, the spindle *i* stops again, the jaws or chucks open, and at that instant a pair of discharging fingers *u* on an oscillating arm *v* are moved forward to seize the finished blank; sidewise, to remove it from the chuck, and backwards into the position shown. When the tail-piece of the fingers comes against a stop *w* on the frame they are opened, and the completed blank drops down the shoot *x* into a receiving vessel beneath.

The whole of the motions above described are self-acting, so that after the rough blanks are thrown loosely into the hopper or trough *a*, they are not touched by the operative until they are removed to the worming machine, where the thread is cut.

In the worming machine, similar means are adopted to feed the blanks into the machine, and to

insert them into the chuck of the spindle, the only difference being such as is incidental to the introduction of the head of the blank into the chuck instead of the end. The thread is cut by a single V cutter, to which the requisite traversing motion is given by means of a mandrel screw and comb.

An ingenious plan has been adopted in these machines to save labour, and consumption of steel in the cutters. The plan has been to turn a ring of tool steel of just such a section on the outer edge that it will fit the finished head of the screw, as shown in Fig. 6813. This ring of steel is then cut into two or more pieces, and each piece forms a cutter of considerable length, which turns both the top and under side of the head, and only requires grinding to the proper angle to keep it in working order until worn too short to use.

See PIN-MAKING MACHINE.

SCREWING MACHINE. FR., *Machine à tarauder;* GER., *Schraubenmaschine;* ITAL., *Macchina da viti;* SPAN., *Máquina para hacer tornillos.*

See MACHINE TOOLS.

SCREW-JACK. FR., *Cric à vis;* GER., *Hebeschraübe;* ITAL., *Cricco a vite;* SPAN., *Gato.*

See HAND-TOOLS.

SEAT. FR., *Siége;* GER., *Sitz;* ITAL., *Sede;* SPAN., *Asiento.*

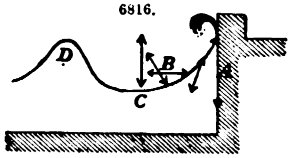
In machinery, a seat is that part upon which another part rests; as a valve-seat.

SEA WALL. FR., *Mur à la Mer;* GER., *See Wall;* ITAL., *Murazzo;* SPAN., *Murallas de mar.*

Sea walls occupy an intermediate position between reservoir walls and breakwaters. They resemble the former in being required to withstand the pressure of still water, and the latter in being exposed to the action of waves. Thus they partake of the nature of both of these structures, and their construction must consequently be in accordance with the conditions which these have respectively to fulfil. The considerations respecting those conditions, and the calculations necessary to duly provide for them, having been already treated at length, we have only to point out briefly their application to the present case, and to describe certain features which are peculiar to it. Frequently, sea walls are erected to protect the land from the encroachments of the sea. In such a case, the structure partakes of the character of a retaining wall, and must be constructed accordingly. But in any case, whether the conditions to which the wall is subject approach more nearly to those of a retaining wall or a reservoir wall, its face is exposed to the action of waves, and it becomes, therefore, important to consider the nature and the effects of this action.

Rankine, who continued the investigations of Scott Russell, states that when waves roll straight against a vertical wall, as in Fig. 6816, they are reflected, and the particles of water for a certain distance in front of the wall have motions compounded of those due to the direct and to the reflected waves. The results are of the following kind;—The particles in contact with the wall, as at A, move up and down through a height equal to double the original height of the waves, and so also do those at half a wave length from the wall, as at C; the particles at a quarter a wave length from the wall, as at B, move backwards and forwards horizontally, and intermediate particles oscillate in lines inclined at various angles.

6816.



It is not essential that the face of the wall should be vertical, as in the figure, in order to reflect the waves; it will reflect them when the batter is considerable. According to Scott Russell, it will do so even with a batter of 45°.

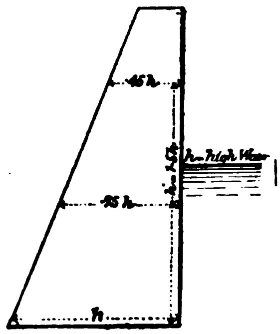
Thus it will be seen that the action of a wave is to lift the stones in the face of the wall against which it breaks, and this fact must be borne in mind in designing the wall. For the same reason, the cope should not project beyond the face, as in such a case it would offer a surface to the crest of the wave. It should also consist of large stones sufficient to resist by their own weight the pressure due to the greatest height of a wave above its bed; they should also be dowelled to each other. Whenever possible, the cope should be raised above the crest of the highest wave when augmented in height by reflection. It has been ascertained that the most powerful action of waves occurs at half-tide when the shoreward current is strong. The largest blocks in the face of the wall should therefore be placed at that level. The fall of the wave when reflected from the face of the wall causes a very severe undermining action at the foot. This action may be resisted by a flat stone pitching having no bond with the wall, or by a bed of concrete 2 ft. broad by 1 ft. thick, joining the wall. A series of groins will also do good service in protecting the foot of the wall. In some cases the undermining action has been diminished by forming the face of the wall into steps, so as to break the descent of the water. This mode of forming the face is, however, very objectionable, and should never be resorted to.

When the wall is of stone, the face should be composed of hammer-dressed ashlar, or block-in-course. In masonry exposed to violent blows from waves, the stones forming the face have a tendency to jump out. This is partly occasioned by infiltrations of water through the joints, which water, being compressed by the blow, exerts a pressure tending to force the stone outwards. To counteract this tendency, when the action of the waves is very severe, the stones of the face may be dovetailed into each other and tabled with the next course. This constitutes the most effective remedy, but it requires to be executed with great care, and it entails a large additional expense. Instead of the dovetailing and tabling, iron cramps may be used; these have been found to be sufficient in many exposed situations. The stones in the face of the Plymouth breakwater are protected by this means. To prevent the infiltration of the water, the outer edges of the joints should be laid in cement. Pointing is insufficient, as the shock of the waves will in a short time cause the cement to jump out. The backing may be of coursed rubble, built in strong hydraulic mortar. Sometimes strong concrete is used as a backing, and in many respects it is superior to rubble masonry for this purpose. As the pressure is concentrated towards the back of the wall at high water, an inferior kind of masonry is not suitable to that position; but a great objection to the employment

of two classes of masonry or two kinds of material in any reservoir or sea wall is the inequality in settling down. This inequality weakens, or in the worst cases destroys altogether, the cohesion of the backing with the face of the wall. All structures of this nature should be homogeneous, and as far as practicable monolithic. For this reason, sea walls have frequently been constructed wholly of blocks of concrete, and when the concrete has been properly proportioned and prepared, such walls are superior, in resisting qualities, to those constructed of rubble faced with block-in-course or ashlar. But better than either, wherever the conditions are suitable, inasmuch as it fulfils perfectly the two conditions of homogeneity and monolithicity, is the employment of concrete in mass for the whole of the wall. Concrete used for this purpose should be strong, and for a depth of about 6 in. from the face should be composed of fine gravel. This gives the face a better appearance, and enables it to withstand better the corroding action of the waves. In some exposed situations, it may even be desirable to slightly increase the proportion of cement in this facing. Where shingle or gravel is readily obtainable, walls may be constructed in this way at half the cost of masonry.

When a sea wall is required to stand alone, that is, when there is no earthern embankment behind it, it must be proportioned like a reservoir wall, the conditions being similar. But in the case of the sea wall, we have an additional force to take into account, namely, that of the waves, and additional strength must therefore be given to the sea wall to render its stability equal to that of the reservoir wall established under similar conditions. It is difficult to estimate the force with which a wave strikes against a vertical surface, but it is in all cases great. As it is delivered in the form of a blow, it takes effect in the most violent manner possible, and to render the wall capable of withstanding the shock with perfect security, the proportions of the reservoir wall will have to be considerably augmented. It is usual, in the latter case, to make the thickness of the wall ·7 h, ·5 h, and ·3 h at the bottom, middle, and top respectively; h being the height of the wall. In a sea wall, the conditions vary so much that it is impossible to lay down anything like an absolute rule; but for exposed situations where a good foundation may be obtained, the following may be relied upon as giving a minimum expenditure of material with ample security. Let h be the depth of still water in front of the wall at high water of spring tides, and h' equal to 1·5 h. Then the thickness of the wall may be h, ·75 h, and ·45 h at the bottom, at half the height h', and at the height h' respectively. The portion of the wall above this height, if any, should be carried up with the same batter. Fig. 6817 represents the cross-section of a wall proportioned by this rule.

6817.



In unexposed situations, where the violence of the waves is not great, or when backed with earth, and especially when the wall is a monolithic concrete structure, the proportions ·7 h, ·5 h, and ·3 h, taken at the heights above indicated, will be sufficient.

A full investigation of the pressures to which this kind of wall is subjected, and a description of the manner of its construction, will be found in the articles Damming and Retaining Walls.

SEWING MACHINE. Fr., *Machine à coudre;* Ger., *Nähmaschine;* Ital., *Macchina da cucire;* Span., *Máquina de coser.*

See Boot-making Machinery, p. 496.

SHAPING MACHINE. Fr., *Machine à limer;* Ger., *Feilmaschine;* Ital., *Pialletta;* Span., *Máquina de tallar.*

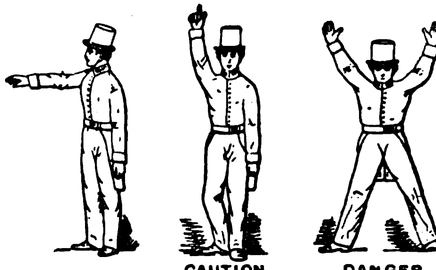
See Machine Tools.

SIGNALS. Fr., *Signaux des chemins de fer;* Ger., *Eisenbahnsignale.*

Railway Signals.—In considering the means to be employed for directing and ensuring the safety of the traffic upon railways, it became evident that among other things some plan should be devised for giving instructions and information to drivers and guards of trains as to the state of the road in advance of them, or of the nearness of a preceding train, so that the speed and progress might be judiciously regulated; the plan ultimately adopted as most suitable was that of the mechanical contrivance known as signals.

Signals chiefly consist of variously shaped boards, painted a bright red colour on one side to indicate danger, and in some cases green on the other to indicate caution; these boards are fastened to a pole or mast attached to a post in such a manner as to admit of their being turned round, raised and lowered, or otherwise altered in position so that in addition to representations by colours certain movements are made.

6820. 6819. 6818.

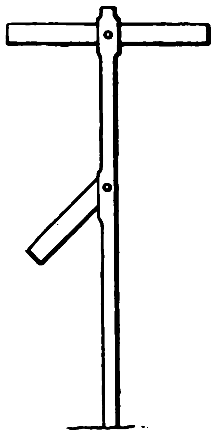


ALL RIGHT — CAUTION GO SLOW — DANGER STOP

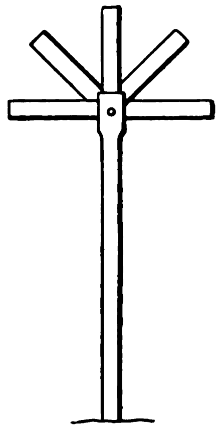
In most cases the engineers or the traffic managers arranged their particular system of signals, fixed or portable, without consideration of those used on other lines, and the natural result is that the forms and systems in use are considerably diversified; the first railways had signals placed only at the principal stations and junctions, the intermediate portions of line were regulated by policemen who had certain beats assigned to them, and who gave manual signals to the drivers as necessity demanded; danger was indicated by facing the approaching train and elevating both hands above the head, Fig. 6818; the go slow or caution signal was given

by one hand similarly held, Fig. 6819, and all right or line clear by extending the right hand from the body horizontally, Fig. 6820. Red, green, or blue, and white flags were used in many instances in conjunction with and also instead of the manual signals; gradually station or home fixed signals were introduced throughout each railway, then distant or auxiliary signals worked by wires having their levers concentrated at one locality, frequently in a cabin or signal box, for facilitating operation by the men in charge; this latter method has now to a great extent given place to a system of interlocking the mechanism for moving the points and signals, and especially at junctions and large stations; these inventions for locking prevent the possibility of an all-right signal being given when the road governed by that signal is fouled in consequence of a train being wholly upon it, or through its being intersected by a train passing from another road.

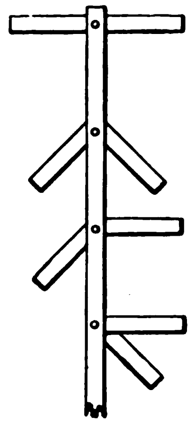
6821.



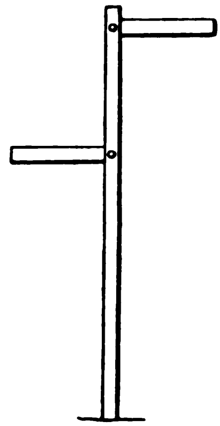
6822.



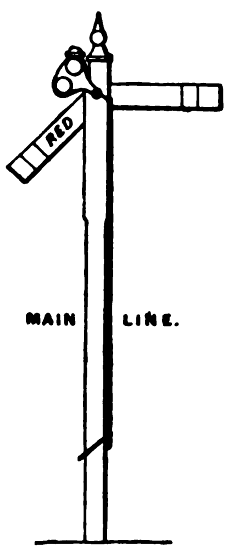
6823.



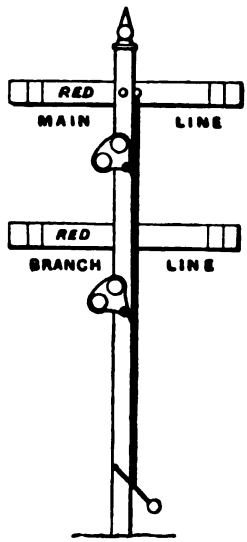
6824.



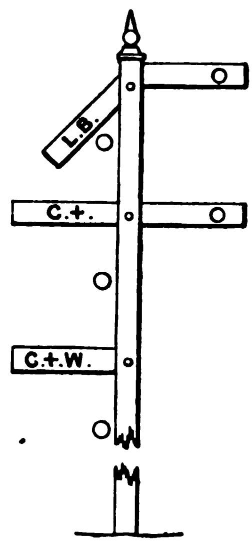
6825.



6826.



6827.

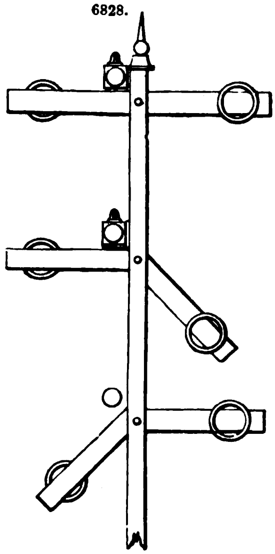


The most general form of signal is that of the semaphore; it is an imitation of the old telegraphy systems, the first of which appears to have been invented by a Dr. Hooke in 1684, Fig. 6821, and revised by a Rev. Mr. Gamble in 1795; it was then styled the radiated telegraph, Fig. 6822; further improvements were made in 1804, and in 1810 by Pasley, by Rear-Admiral Popham in 1816, Fig. 6823, and by Pasley or Macdonald in 1822, when the system was termed the Universal Telegraph, Fig. 6824; it was similar in detail to the French coast semaphore in use in 1803.

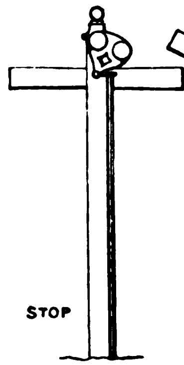
The semaphore signals as used on the railways are constructed with arms upon both sides of a mast fixed upon a centre pin free to move up and down; those on the left-hand side, as seen when facing the signal, are as a rule to govern the left roads, and there are as many arms as roads or descriptions of trains to be regulated, Figs. 6825, 6826. It has been found desirable to further distinguish the arms by numbers or letters painted upon them, or by affixing pieces of shaped iron or board, corresponding with the understood number or letter of the several roads, Figs. 6827, 6828.

On the Hull and Holderness line the arms were moved upon a pin placed in the centre of its length, Figs. 6829, 6830, and a similar method is adopted in situations where there is little room or where masts cannot be erected, as upon the London underground railways, Figs. 6831 to 6833, and Victoria Station, London, Chatham, and Dover Railway, Figs. 6834, 6835.

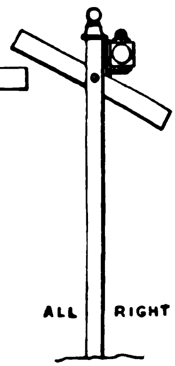
6828.



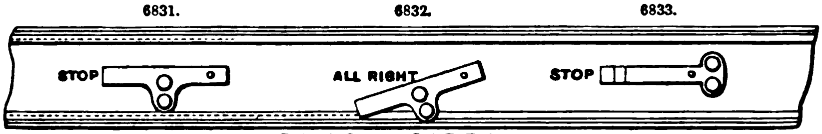
6829.



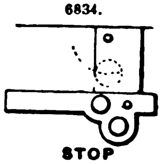
6830.

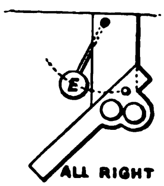


6831. 6832. 6833.



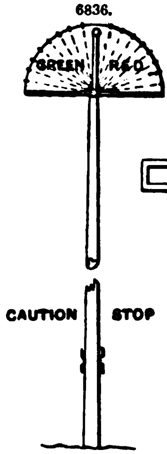
6834.



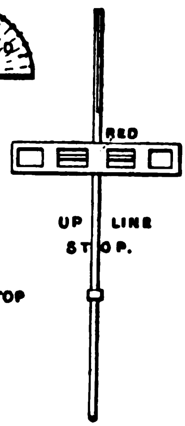


6835.

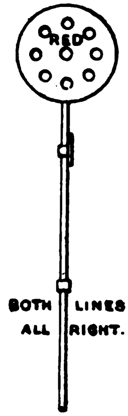
6836.



6837.



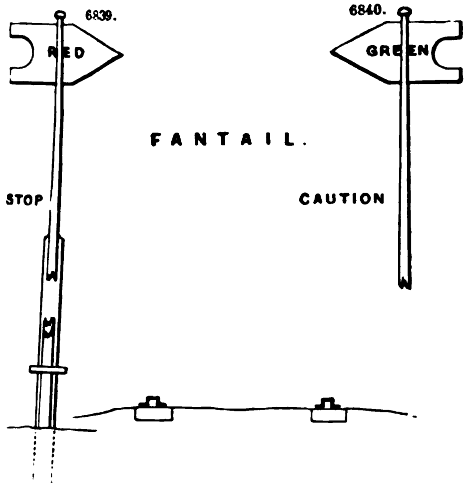
6838.



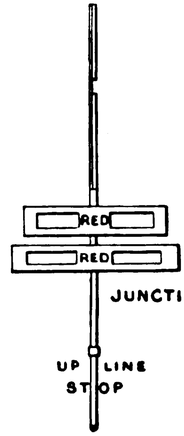
The fixed signals formerly in use on the Great Western were red and green flags stretched upon semicircular hoops attached to a mast, and drawn open and close by means of cords and pulleys, Fig. 6836; these were abandoned for the cross-bar and disc painted red, Figs. 6837, 6838, and fantail painted red on one side and green on the other, Figs. 6839, 6840. The down line cross-bar is distinguished from the up line by having two downward ears affixed to the ends of the bar. Junction signals have double discs and cross-bars, Figs. 6841, 6842. The fantail signal is considerably lower than the cross-bar, and is principally used for giving the caution, Fig. 6840; the danger is shown by Fig. 6839. The cross-bar and disc form has been proved to be the most clearly discernible at a great distance.

The Lancashire and Yorkshire Railway has spectacle discs fixed to masts which turn round, Figs. 6843, 6844; similar discs for distant signals are used on the Brighton line, but instead of turning round they are made to rise and fall by a balance weight on a short lever, Figs. 6845 to 6847.

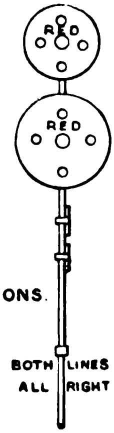
6839. 6840.



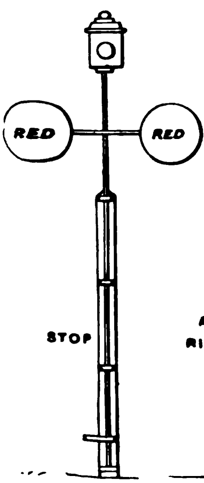
6841.



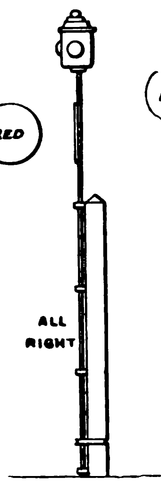
6842.



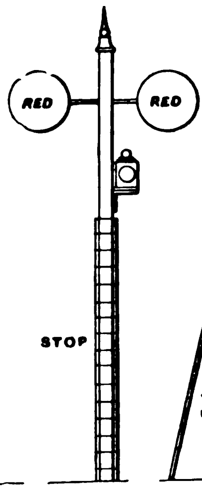
6843.



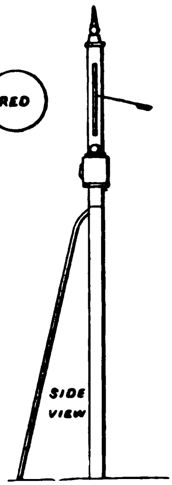
6844.



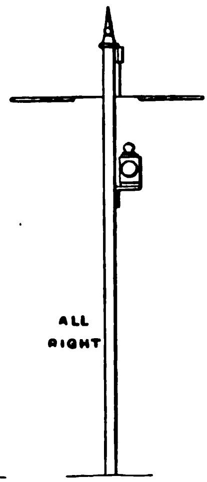
6845.



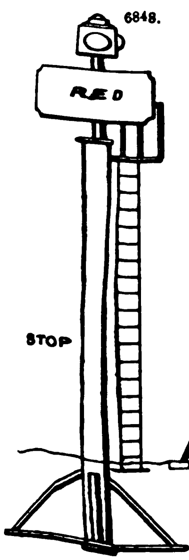
6846.



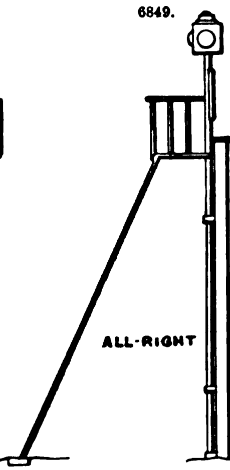
6847.



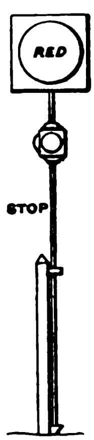
6848.



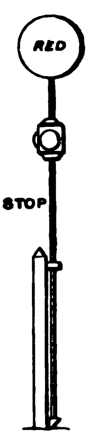
6849.



6850.



6851.



6852.

6853.

The distant signals of the Midland Railway consist of a rectangular board painted red and affixed to a turning post, Figs. 6848, 6849.

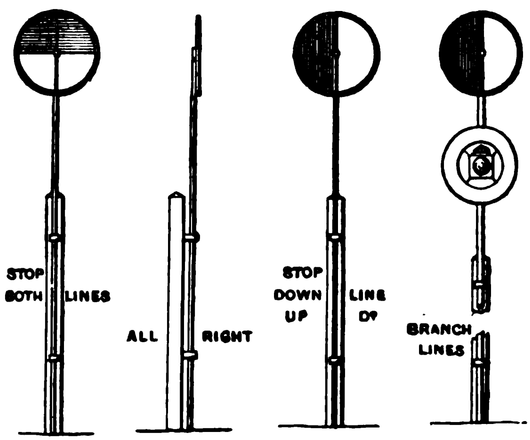
Circular and square discs are used on the North-Eastern Railway, Figs. 6850 to 6853.

The original signals of the South-Western were semi-discs placed on a pin within a ring, Fig. 6854, and capable of revolving by means of ropes and pulleys; those for the station and distant have the disc fixed to the ring, Figs. 6855, 6856, the mast being turned round. Branch-line signals have a wide green ring fixed round a lamp below the ordinary disc, Fig. 6857.

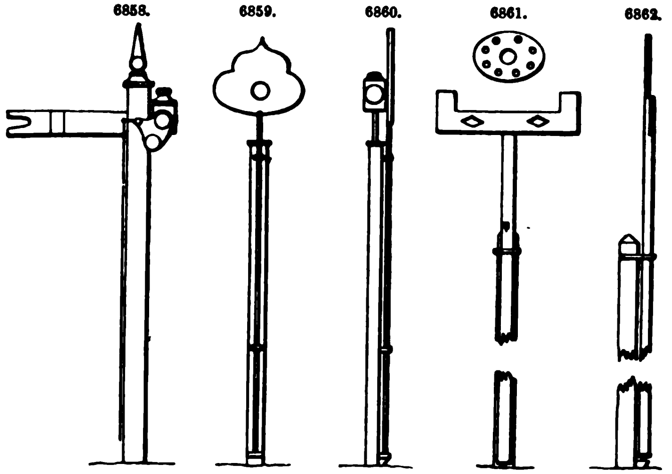
The forms of special signals are as various as the general ones; the following exhibit a few examples;—Fig. 6858 is a semaphore on the South London line; Figs. 6859, 6860, are used at the Broad-street station for starting trains; Figs. 6861, 6862, at the Camden goods shed, Chalk Farm; Fig. 6863, a signal on the Blackwall line; Figs. 6864, 6865, on the Brighton and South Coast.

Foot signals and lights attached to points to indicate their position

6854. 6855. 6856. 6857.



6858. 6859. 6860. 6861. 6862.

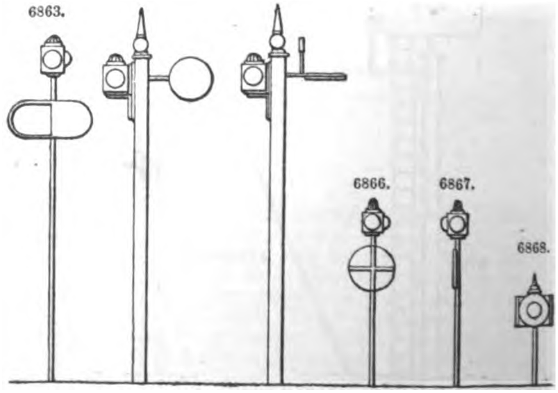


are extensively used and variously constructed, principally with small discs affixed to the top of the lamp, and which turn with the throw of the points, Figs. 6866 to 6868.

Several lines have adopted a platform starting signal, in most cases consisting of a miniature semaphore, worked from the cabins, and frequently in connection with a main signal beyond and outside the station. Where these are in use manual signals are prohibited, and no driver may start his train until the arm is lowered.

Many branch-line and other junctions have the points attached to an indicator, the invention of John Stevens, in 1862, Figs. 6869 to 6871, when they are not interlocked with the main signals, so that the drivers may see at some distance whether or not they are properly set. The points must be quite close to the rail to admit of the green or white light being seen. If the white light shows, the line is right

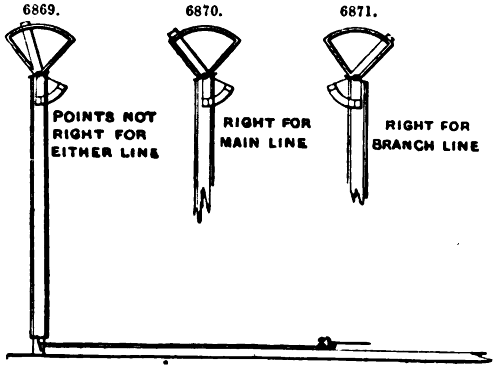
6863. 6864. 6865. 6866. 6867. 6868.



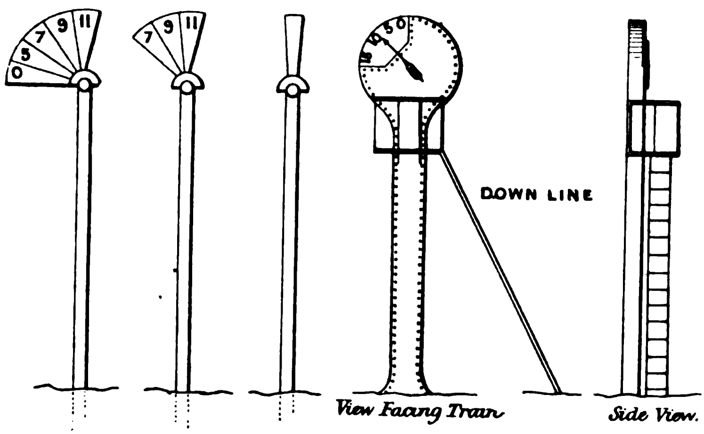
for the main line; if the green, it is clear for the branch; and if the red, the points are not in a position for either line.

Among the early attempts in signal construction, three may be noted as possessing some novelty. In 1838 a disc signal was in use at the Vauxhall Bridge, Birmingham, the invention of a Dr. Church; it was connected to the points and stood about 5 ft. high; two discs, 2 ft. in diameter, were fixed on the top at right angles to each other, and surmounted by a lamp showing two red lights, one blue and one white; the discs were painted with colours to correspond. In 1842 C. Hall introduced a system on the Great Eastern line; the signal consisted of five leaves placed in the shape of a fan on a mast, and coloured yellow, green, red, and white, Figs. 6874 to 6876; each leaf indicated the time a train had passed it; a green post was fixed

6869. 6870. 6871.



6872. 6873. 6874. 6875. 6876.



at the side of the line 100 yds. in advance of the signal, beyond which no train was to pass if the fan exhibited the red leaf; a green and white striped post was also fixed at a mile beyond the signal; and if the fan showed the seven or nine minute colour when passed, the driver might put on moderate or full speed on reaching the striped post. These signals were in use several years.

On the Greenwich Railway plain posts were fixed to each road at half a mile on either side of the junction, on reaching which the driver opened the engine whistle, and the switchman notified by hand-flags which train was to proceed on to the main line.

The construction of self-acting, or rather train-actuated signals, has claimed the attention of a very large proportion of inventors of signals, but very few systems have been tried, and many of those were found practically unreliable and therefore useless.

Whitworth's signals were used on the Brighton line, at some of the tunnels on the Lancashire and Yorkshire, Whiston Bank, near Liverpool, and several other situations. In 1858 Baranowski obtained permission to test his automaton distant signal between Hackney and Kingsland, on the North London line. It was set to danger by the passing train pressing down a lever which actuated the mechanism of the signal; and when the train reached a distance of 1100 yds. it pressed down another lever, causing the danger signal previously set to be released. Although many hundreds of trains successfully worked it, its failure on one occasion is supposed to have caused an accident which led to its being removed.

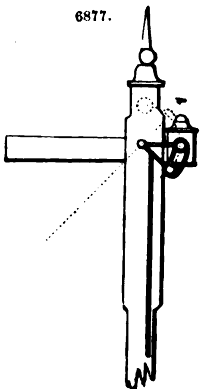
The Midland Company erected an indicator at Kegworth in 1863, Figs. 6875, 6876, showing the time a train had passed up to fifteen minutes. It was set in motion by a treadle being depressed by a passing train. At the expiration of fifteen minutes the pointer returned to zero. This signal was subsequently removed as unreliable.

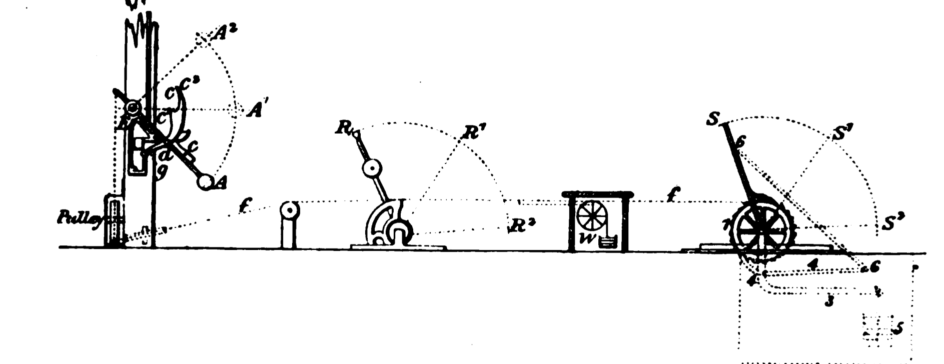
So soon as the few inventions at all trustworthy for locking signals and points had proved their advantages over previous systems, they were rapidly adopted by many of the railway companies. It would be impossible in a limited space to explain and illustrate all the devices proposed for working these signals; but the following examples, among many equally good, will convey a clear idea of the methods introduced and in work.

Fig. 6877 is an example by Stevens, in 1854, for giving the three semaphore indications by one wire. A is a weighted lever connected by a rod with the arm and lamp. The lever is actuated by one of the levers R or S, and the wire and chain connection *f*. The drawing shows the signal in its normal state.

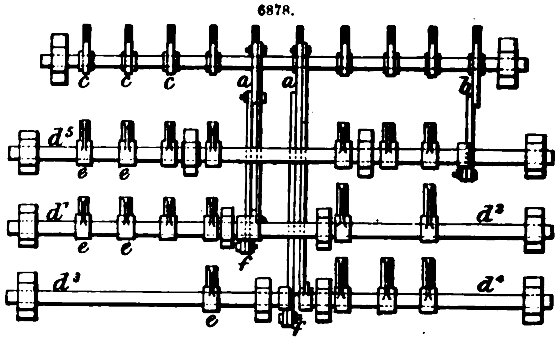
The caution signal is thus produced. The levers R, S, must be moved to the position R¹ S¹, lifting the lever A to the position A¹, where it will be retained by the stud fixed to apparatus on the lever A, which is brought into position by the stud d on the small lever. When the all-right signal is to be given the levers R, S, must be still further moved to the positions R², S², which will similarly move lever A to A², with its shorter end resting on the stop E, when the apparatus may be returned to its original position. To give the danger signal the stud on lever A during the return movement passes over the surface c^1 on lever c, the lever A being meanwhile supported by projection g.

6877.





6878.

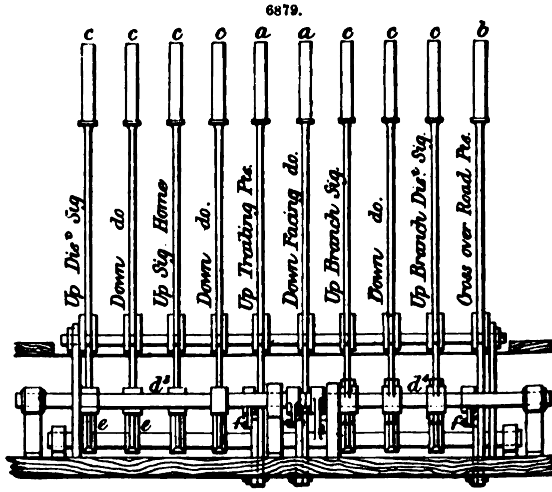


The chain or wire is attached to the periphery of the ratchet 1, turning freely on its axis. S is a lever, acting on the ratchet-wheel, which is retained in position by the weighted lever 3. This lever has a pawl 4, which takes the teeth of the ratchet-wheel, so as to retain it in its position. When pulled over by operator, 6 is a chain connecting the lever and pawl in order to release the pawl for the return movement.

Figs. 6878 to 6881 illustrate the invention of F. Brady, Engineer to the South-Eastern Railway.

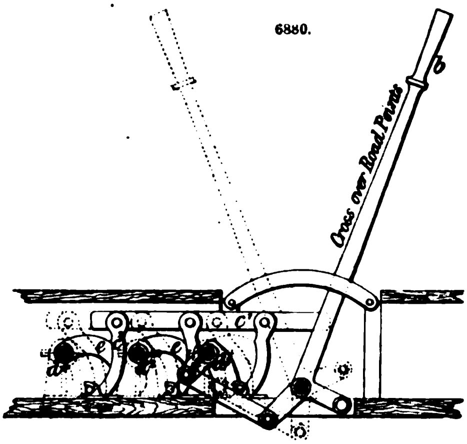
Fig. 6880 is an end view of the apparatus. Fig. 6879 is front elevation of the same. a, a, are the two point levers of the main and branch lines; b is a lever which works both the points of the cross-over road; c, c, are levers connected with the several signals, having the name of the signal or point written upon them. d^1 to d^5 are horizontal spindles, on which the locking axes e, e, are fixed. f, f, are the moving cranks. They are shown in the position they occupy when the main lines are open and the branch closed. To each of the signal levers c there are jointed horizontal bars c^1, which are connected by links c^2 to the floor by means of shoes, in which the short links turn; the links so connected with each signal lever are

6879.

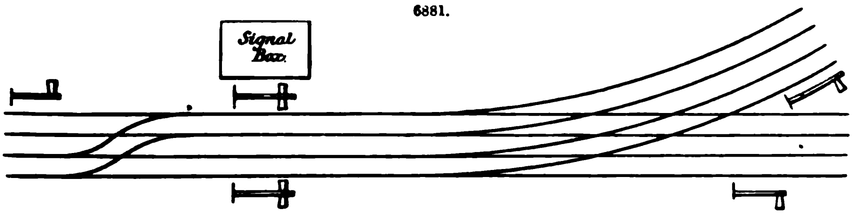


always parallel to the lever, and against them and against the levers the locking axes on the horizontal axes act. In the drawing the signal levers are as standing at danger, and consequently the point levers are all free. If the trailing point lever is moved from its present position to a position to suit trains coming from the branch on to the main line, it, by means of links connecting it with the arms f on the axes d^1, d^2, causes these axes partially to rotate, and in so doing it removes the locking axes from the links c^2 of such of the branch signals as may then be lowered, whilst at the same time it moves other locking axes, c, in front of the links c^2 of the main-line signal levers, which require to be held at danger. In a similar way the facing point lever, when moved over to suit trains entering on the branch line, gives motion to the axes d^3, d^4, and by means of the locking axes upon them unlocks such of the branch signals as may require to be lowered whilst it locks any of the main-line signals which require to be then maintained at danger. The point lever b of the cross-over road when moved over closes both the points of the cross-over road, and at the same time causes the axis d^5

6880.



6881.



partly to rotate, and brings up the locking axes thereon so as to lock all the signal levers at danger.

This system is applicable at junctions where a greater number of point levers is required, each point lever in the manner described being caused to give motion to a separate axis or axes, with locking axes thereon to lock and free the signal levers.

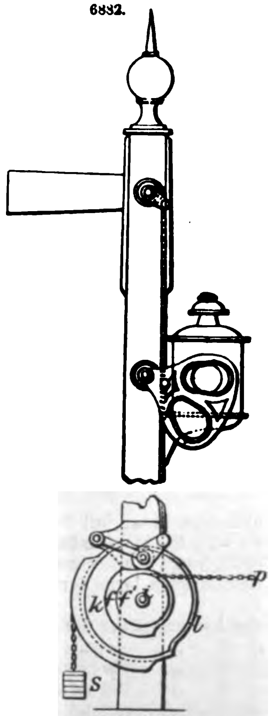
Figs. 6882 to 6892 were introduced in 1867 by Saxby and Farmer.

Figs. 6882, 6883, also illustrate a method of actuating repeating signals when the distant is too far to be visible to the signalman.

The signalman, working in his box upon the distant signal lever, sets a wire in motion, one end of which is connected to the apparatus in the box, whilst the other is fastened on a cam f, the periphery of which is shaped to correspond to the duties assigned thereto. This cam consists of a pulley or roller f^1, upon which bears the chain p, and the wheel proper f, on the flat portion of the circumference of the latter bears a small roller connected with the cranked lever h. The wheel f revolves freely upon its axis i, fitted to the side of the post, and by the partial revolution of the wheel f the cranked lever h is acted upon, and one arm of this lever acts by a rod upon the semaphore or lamps. Suppose the cam-wheel to describe a limited arc of a circle, the signal denotes caution, and the chain p may be pulled as soon as the signal has spoken.

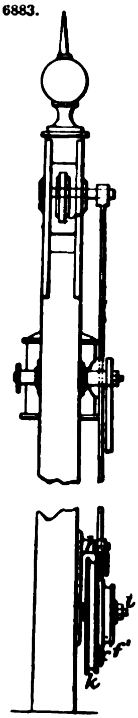
If the lever in the box is closed, and the signal denotes danger, the weights S cause the cam-wheel to turn, being attached to the circumference of the pulley K, which revolves freely on the axis i, and to maintain the distant signals at danger as a normal condition, the pulley k is furnished with a ring, projecting upon its side, upon which bears the axis of the lever h, and by the action of the weight S the danger position of the semaphore is preserved, as the lever h can act only if the axis of the

6882.



Front View.

6883.

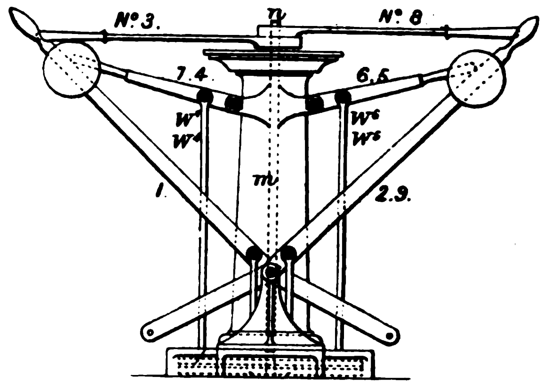


Side View.

lever h is displaced by the motion of the wire p. By this plan one wire will actuate both distant and repeater signals.

Figs. 6884 to 6887 show a plan for a vertical motion of the locking between points and signals in cases where there may be little room. In this arrangement the slides and locks give way to circular stop-plates A B¹, A B², one of which is fastened to the bottom of the vertical shaft n, moved by the point lever No. 8; the other upon the hollow shaft m, enclosing n, and moved by the point lever No. 3. These two point levers describe here areas of circles in a horizontal direction, as will be easily understood, and the rods working the points themselves are fitted to the bottom of the solid or hollow shaft respectively. The circular plates A B¹, A B², are furnished with slot-holes or with notches in the edge corresponding to the holes or slots shown in the stop-plates, Figs. 6886, 6887.

6884.

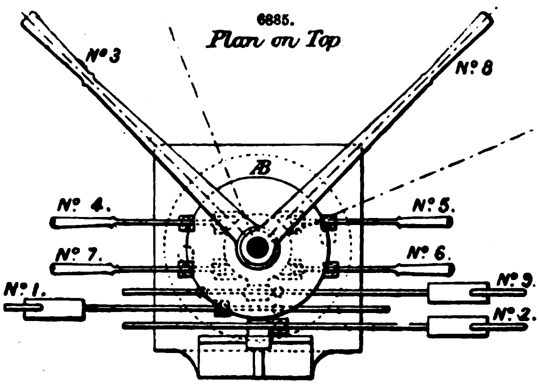


Elevation.

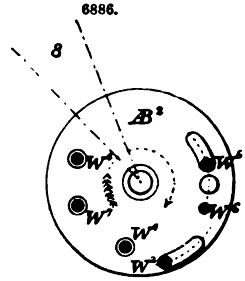
Each signal lever is connected to a vertical rod W, worked in a manner

6885.

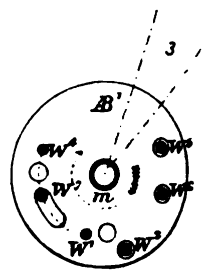
Plan on Top



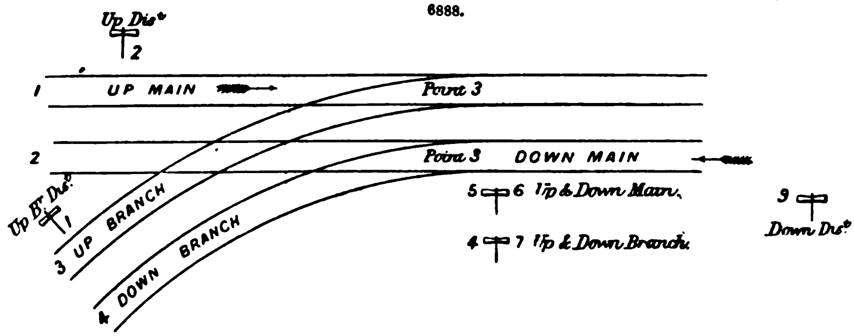
6886.



6887.



6888.



similar to a horizontal apparatus; but in combination with the point levers Nos. 3 and 8 in their respective connection with the stop-plates A B¹, A B², which they work.

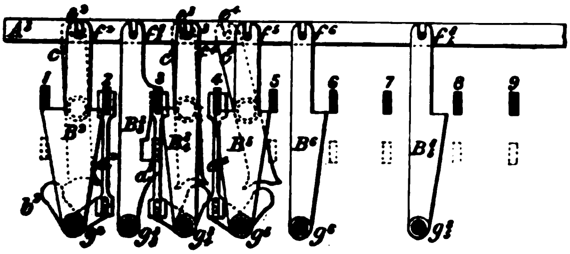
Figs. 6888 to 6892 illustrate a horizontal apparatus, as generally used, for a junction, and also when extended in details for a large terminus. The following schedule shows the duty of each of the levers;—

Lever 1	actuates	the distant signal of	up branch line, 3.			
„ 2	„	„ „	up main line, 1.			
„ 3	„	the points of up lines, 1, 3.				
„ 4	„	the station or junction signal of	up branch line, 3.			
„ 5	„	„	down main	„	„	1.
„ 6	„	„	„	„	„	2.
„ 7	„	„	branch	„	„	4.
„ 8	„	the points of down lines 2, 4.				
„ 9	„	the distant signal of down lines 2, 4.				

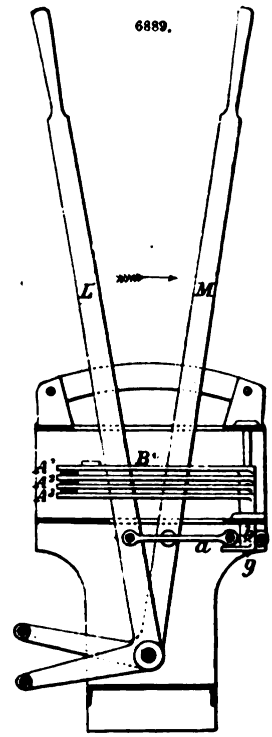
This arrangement is for nine levers with three slides one over the other.

Fig. 6889 is a vertical section across the frame; the slides are marked A^1, A^2, A^3, each of which is connected with a certain number of main locks. Fig. 6892 shows slide A^1 in plan, with locks and pins. Figs. 6891, 6890, similarly show slides A^2 and A^3, and the whole of the levers are indicated only in Figs. 6890, 6892, where they are numbered in accordance with schedule. In Fig. 6889 the two point levers only are shown in elevation; the lever L being closed, or in its extreme position towards the front, and M open, or in its extreme position towards the back of the frame.

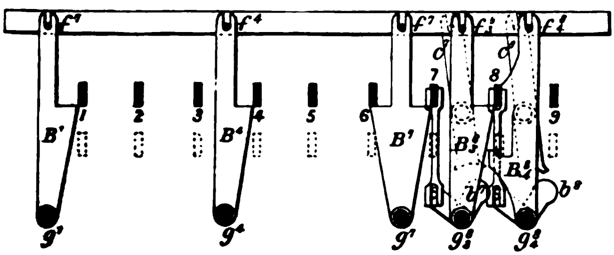
6890.



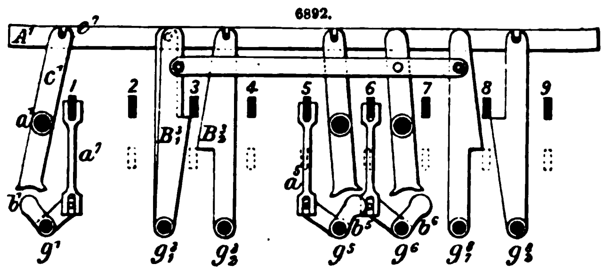
6889.



6891.



6892.



If the lever L is moved in the direction of the arrow, the forked lever a connected to L is set in motion; a again actuates the cranked lever b, one arm of which is connected with the forked lever a, whilst the other bears upon the concave surface of the lever arm c, and causes the latter to vibrate on its fulcrum d, in either direction; the other arm of the lever c bears by means of a fork-piece upon a pin e, fitted respectively to the top or bottom surface of any one of the slides A. The motion of the hand-lever L being thus communicated to the straight lever c; the latter in its turn imparts a longitudinal motion to the slide a.

The slides A are fitted with another series of pins f, fitting into the fork-shaped heads of the locks B, which are thus caused to describe arcs of circles in pivoting upon their axes g. The locks B are iron stop-plates cut at a right angle, upon one side of which the respective hand-lever bears when it gets into a certain position, which, it will be readily understood, takes place upon the locks, partially revolving or pivoting round their axes g. The inclined sides or planes are intended to assist the other mechanisms, seeing that the hand-lever bears upon such an inclined plane if its open position is converted into a closed one, and thus the shutting of the levers is facilitated and accelerated.

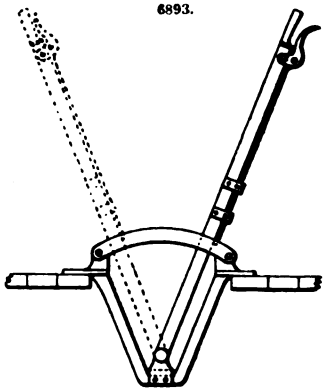
The general effect may be explained thus;—

By opening lever No. 1, then No. 3 is locked in its open and 8 fixed in its normal position.
" " 2, " No. 3 is locked in its normal position.
" " 3, " Nos. 2, 5, and 6, are locked in their normal positions, and 1 and 4 unlocked.
" " 4, " No. 3 is locked in its open and 8 in its normal position.
" " 5, " No. 3 is locked.
" " 6, " No. 3 is locked and 8 in its open position.
" " 7, " No. 8 is locked.
" " 8, " Nos. 1, 4, and 7, are locked, and 6 unlocked.

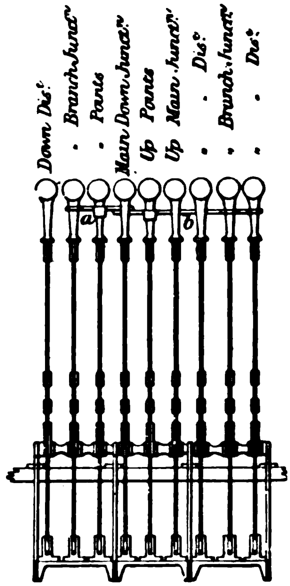
Signal lever No. 9 not being connected with the points is omitted in this schedule.

Fig. 6893, 6894, show a plan introduced by R. C. Roper in 1869. The advantages of this system are, that the locking is accomplished without any moving bolts, cranks, or screws, the long bars on the point levers which effect the locking are in sight, and the operator can see which levers can be moved and which cannot.

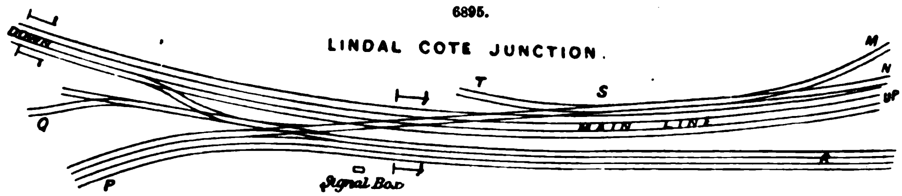
6893.



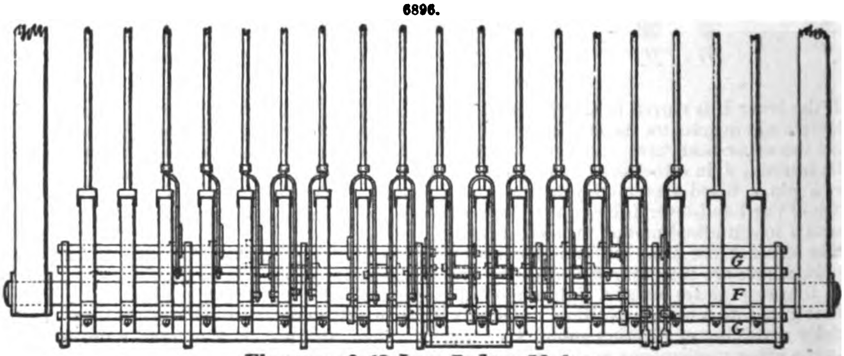
6894.



6895.



6896.



Elevation of 18 Lever Locking Machine

A bar is mounted on the point levers extending between the signal levers, dividing them into sets, and as respects each point lever in motion either way separating the signal levers, which must precede the point levers in their movements from the others. The levers are all arranged in a frame in the usual way; one side of the frame is termed permission for main line, and the other permission for branch line.

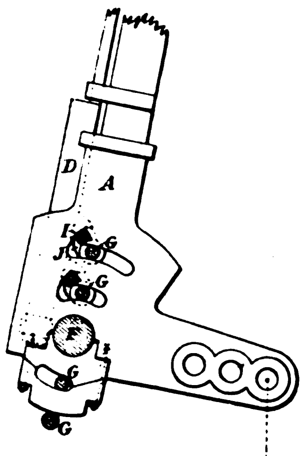
On each point lever is fixed a bar, the bar on one set being lower or higher than that on the other, extending as above described, and so coupled with the signal levers that if there be arranged on that side of the frame called permission for branch line all those signal levers belonging to the main line, and on the opposite side of the frame those signal levers which belong to the branch line, all the signals will be then at danger.

The bars on the point levers extend over the point levers in such a manner, that on either point

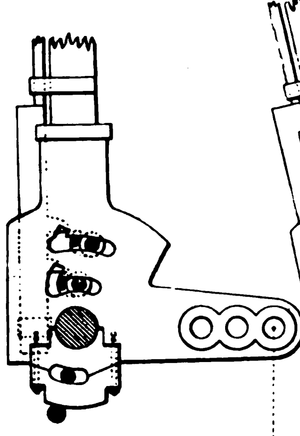
being brought over to one side of the frame, the bar upon it rests against those signal levers which ought to be locked by it when in this position, and the signal levers which are ranged on the other side of the frame are no longer locked by this lever.

The side of the frame which gives permission to the main line gives danger to the branch, and the reverse; but in no case can the signal levers be moved before the point levers.

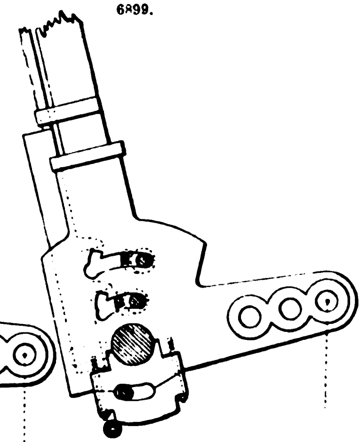
6897.



6898.



6899.



A system invented by Wm. Baines, Figs. 6895 to 6897, is in use at the somewhat complicated junction at Lindal Cote, it having a cross-over road running into both up and down main lines, two branch lines, M, N, on one side, and three lines, P, Q, R, on the other. There are catch-points at S on the up side, which have to be kept closed for the cross-over road and open for the catch-siding T, so that the main lines may not be fouled by traffic on the M and N lines; these catch-points can only be opened for the cross-over road when the signals have been set to danger for the main lines and the branch lines on the opposite side; consequently nine points and seven signals have to mutually interlock with the one set of points at S. Fig. 6895 is a plan of the junction; Fig. 6896 shows the elevation of the lever-frame for eighteen levers; Figs. 6897 to 6899 represent the rocking shafts G and main shafts F in various positions during the pull over. The levers are all centred on the shaft F, and above this is the shaft G, which passes through a quadrant arc in the foot of each lever A, thus allowing the required range of motion. On the shaft G are loosely slipped a number of short tubes or rockers J; these have cams upon them, which act against projecting tappets fixed one upon the bottom of each locking bar, and when the cam is held up under one of these tappets it prevents the bar from being pushed down, in which case the detent of that lever cannot be raised out of the quadrant notch. The practical result of this arrangement is, that before the lever has been moved $\frac{1}{4}$ in. in the quadrant the locking of the second lever is perfectly effected; the pressure upon the several parts is very small, and they do not require oiling.

The existing arrangements for working the traffic on the London Metropolitan Railway and at the Victoria and Cannon Street stations are good examples of the application of locking gear to signals and points, and the facilities for safety afforded thereby have been recognized by the English Board of Trade, and strong recommendations are embodied in the regulations issued by that department that all railway companies should adopt such means for the prevention of accidents.

SILVER. Fr., *Argent;* Ger., *Silber;* Ital., *Argento;* Span., *Plata.*

Silver is a white metal of remarkable brilliancy. It occupies the second rank for malleability, being next to gold in this respect. Its ductility and tenacity are also very great. One grain of the metal is capable of yielding 400 ft. of wire, and a wire with a diameter of $\frac{1}{12}$ in. will support a weight of about 188 lbs. Atomic weight = 108. Molecular weight = 216. Specific gravity = 10·53. Silver fuses at a temperature of about 1873° Fahr., and if allowed to cool slowly, it crystallizes in voluminous octahedrons. When in a state of fusion, it absorbs a considerable quantity of oxygen, which it expels in the act of solidification, with a peculiar sound technically known as spitting. It may be distilled by means of the oxy-hydrogen blow-pipe, and its vapours assume a green colour. The absorption of oxygen by silver in a state of fusion must be regarded as a simple solution of the oxygen in the liquid metal, and not as a combination. When allied with a small quantity of gold or copper it loses this property.

Silver is frequently met with in a native state, but not in sufficient quantities to satisfy the demand for it. The metal, as obtained for use, is chiefly extracted from its sulphide. The metallurgical operations necessary for this extraction are somewhat complicated; but they are based upon the fact that both lead and mercury have a strong affinity for silver. The sulphide of silver is converted into a double chloride of silver and sodium, which is then acted upon by mercury. The mercury then passes into the state of a chloride and liberates the silver, with which it forms an amalgam. From this amalgam the silver is extracted by evaporation. A more recent process depends upon the solubility of chloride of silver in a hot solution of common salt and its separation again on cooling.

In the first of these processes, which is known as the American method, amalgamation and reduction are carried on simultaneously, and the whole of the operation is performed without the application of heat. In the second process, which is practised at Freiberg in Saxony, amalgamation and reduction are two separate and distinct operations, and the chloridation is effected by means of heat.

Silver is naturally soft, but it becomes harder when allied with copper. It is for this reason that it is usually combined with small quantities of the latter metal in order to render it more capable of being conveniently worked. It is not affected by exposure to the air at any temperature, but it is rapidly oxidized by ozonized oxygen. Hydrosulphuric acid blackens silver by producing sulphide of silver and hydrogen.

$$\underset{\text{Silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}} + \underset{\text{Hydrosulphuric acid.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}S} = \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}} + \underset{\text{Sulphide of silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}S}$$

Sulphuric acid attacks silver only when concentrated and at boiling heat; in this case sulphurous anhydride and sulphate of silver are produced.

$$\underset{\text{Sulphuric acid.}}{2\left(\left.\begin{matrix}S\Theta_2\\H_2\end{matrix}\right\}\Theta_2\right)} + \underset{\text{Silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}} = \underset{\text{Sulphate of silver.}}{\left.\begin{matrix}S\Theta\\Ag_2\end{matrix}\right\}\Theta_2} + \underset{\text{Water.}}{2\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Sulphurous anhydride.}}{S\Theta_2}$$

Nitric acids attack silver cold, but more especially when heated, producing nitrate of silver and binoxide of nitrogen.

$$\underset{\text{Nitric acid.}}{8\left(\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Silver.}}{3\left(\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}\right)} = \underset{\text{Nitrate of silver.}}{6\left(\left.\begin{matrix}N\Theta_2\\Ag\end{matrix}\right\}\Theta\right)} + \underset{\text{Water.}}{4\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Binoxide of nitrogen.}}{2N\Theta}$$

When at a red heat, silver decomposes hydrochloric acid, forming chloride of silver and liberating hydrogen.

$$\underset{\text{Silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}} + \underset{\text{Hydrochloric acid.}}{2\left(\left.\begin{matrix}H\\Cl\end{matrix}\right\}\right)} = \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}} + \underset{\text{Chloride of silver.}}{2\left(\left.\begin{matrix}Ag\\Cl\end{matrix}\right\}\right)}$$

A prolonged contact of silver with a solution of chloride of sodium gives rise to the formation of a certain quantity of double chloride of silver and sodium, which dissolves, and the liquor becomes alkaline.

Silver forms with each of the monatomic metalloids a single compound. There are known a chloride, a bromide, an iodide, and a fluoride of silver.

Chloride of Silver, $\left.\begin{matrix}Ag\\Cl\end{matrix}\right\}$.—Chloride of silver exists in a native state crystallized in octahedra. As it is insoluble, it may be readily obtained by precipitating the solution of a salt of silver by hydrochloric acid, or by a soluble chloride.

$$\underset{\text{Nitrate of silver.}}{\left.\begin{matrix}N\Theta_2\\Ag\end{matrix}\right\}\Theta} + \underset{\text{Hydrochloric acid.}}{\left.\begin{matrix}H\\Cl\end{matrix}\right\}} = \underset{\text{Chloride of silver.}}{\left.\begin{matrix}Ag\\Cl\end{matrix}\right\}} + \underset{\text{Nitric acid.}}{\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta}$$

The chloride of silver forms in this case a white flocculent mass. Chloride of silver is absolutely insoluble in pure water. At a temperature of 50° Fahr. salt water dissolves a quantity equal to $\frac{17}{10000}$ of the weight of the salt which it contains; at 64°, $\frac{24}{10000}$; at 212°, $\frac{40}{10000}$; and at 32°, hardly any. Chloride of silver dissolves readily in hyposulphite of soda, cyanide of potassium, and ammonia; hydrochloric acid also dissolves it, but only in very small quantities. By evaporation from its ammoniacal or hydrochloric solution, chloride of silver crystallizes in octahedra identical with the natural crystals. The chemical rays of the spectrum exert a strong action upon this chloride. When exposed to the direct rays of the sun, it immediately becomes violet; in a diffuse light, the colouration manifests itself more slowly. When exposed to a red or a yellow light, which does not contain any chemical rays, it retains its white colour. At a temperature of 500°, chloride of silver fuses; on cooling it assumes the appearance of horn, and is sufficiently soft to be capable of being cut with a knife. In this state it is known as horn silver. At a very high temperature it gives off vapours. Nascent hydrogen reduces chloride of silver cold, and free hydrogen reduces it with the application of heat. In the latter case, however, traces of chloride always escape the reducing action; this fact, which has been clearly proved by Lieben, renders all analytical processes founded upon this reduction incorrect. When not in a state of fusion it is reduced by iron and by zinc. If a little moist chloride of silver be put together in a heap, and an iron rod placed in the centre, reduction is effected slowly from the centre outwards. Mercury reduces chloride of silver, as does also the protochloride of copper.

$$\underset{\text{Protochloride of copper.}}{Cu_2\,Cl_2} + \underset{\text{Chloride of silver.}}{2\,Ag\,Cl} = \underset{\text{Bichloride of copper.}}{2\,Cu\,Cl_2} + \underset{\text{Silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}}$$

When chloride of silver is boiled in a concentrated solution of potassa, oxide of silver is formed, and if sugar has been added to the solution, silver is obtained in an extremely pure state. Heated to a white heat, with carbonate of potassa and marine salt, it is reduced and gives a button of metallic silver. The marine salt renders the scoria more easily detachable.

$$4\left(\begin{matrix}\mathrm{Ag}\\ \mathrm{Cl}\end{matrix}\right\}\Big) + 2\left(\begin{matrix}\mathrm{C}\Theta\\ \mathrm{K}_2\end{matrix}\right\}\Theta_2\Big) = 2\,\mathrm{C}\Theta_2 + \left.\begin{matrix}\Theta\\ \Theta\end{matrix}\right\} + 2\left(\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\Big) + 4\left(\begin{matrix}\mathrm{K}\\ \mathrm{Cl}\end{matrix}\right\}\Big)$$

Chloride of silver. Carbonate of potassa. Carbonic anhydride. Oxygen. Silver. Chloride of potassium.

The metallic sulphides, especially those of the electro-positive metals, give the double decomposition with chloride of silver.

Bromide of Silver, $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Br}\end{matrix}\right\}$.—Bromide of silver is found in a native state, and may be obtained by the same processes as the chloride, nearly all the properties of which it possesses. It is distinguished from the chloride by a less degree of solubility in ammonia, and by the action which light exerts upon it; for when prepared by artificial light it is white, but if exposed to the diffuse light of day, it instantly becomes of a yellow hue, and it keeps this tint without alteration, whatever be the intensity of the light to which it may afterwards be exposed. Bromide of silver is found in Mexico, where it is known as Plata verte, or green silver, in the form of small crystals or crystalline granules of a pale olive-green tint.

Iodide of Silver, $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{I}\end{matrix}\right\}$.—Iodide of silver is prepared in the same way as the chloride and bromide, and like the latter compounds, it exists in a native state. It is hardly soluble in ammonia; light affects it very readily, causing it to change from the yellowish tint which is its natural colour, to bister, and then to black. Iodide of silver occurs native in several Mexican mines in the form of thin, pearly, flexible scales.

Silver forms several compounds with the diatomic metalloids. With sulphur it forms a sulphide corresponding to the formula $\mathrm{Ag_2\,S}$. With oxygen, it gives three compounds, the suboxide $\mathrm{Ag_4}\,\Theta$, the protoxide $\mathrm{Ag_2}\,\Theta$, and the binoxide $\mathrm{Ag_2}\,\Theta_2$. Of these three oxides, the protoxide alone possesses any interest.

Sulphide of Silver, $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\mathrm{S}$.—Sulphide of silver occurs native, sometimes crystallized in cubes, and sometimes in masses. This is the principal ore of silver. It may be obtained artificially by precipitating a salt of silver by hydrosulphuric acid.

$$2\left(\begin{matrix}\mathrm{N}\Theta_2\\ \mathrm{Ag}\end{matrix}\right\}\Theta\Big) + \left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\mathrm{S} = 2\left(\begin{matrix}\mathrm{N}\Theta_2\\ \mathrm{H}\end{matrix}\right\}\Theta\Big) + \left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\mathrm{S}$$

Nitrate of silver. Hydrosulphuric acid. Nitric acid. Sulphide of silver.

Sulphide of silver is naturally black; but when it has been fused or raised to a high temperature, it assumes a metallic appearance. Native sulphide always has this appearance, and hence it has received from mineralogists the name of silver glance. Its specific gravity is 7·2. When subjected to roasting, sulphide of silver loses sulphurous anhydride and leaves metallic silver. If roasted with marine salt, it is converted into chloride; it is also converted into the latter substance if allowed to remain a long time in contact with bichloride of copper.

Protoxide of Silver, $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\Theta$.—This oxide is obtained in the form of a brown and heavy powder by precipitating a salt of silver by hydrate of soda or potassa. In this case, a hydrate $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{H}\end{matrix}\right\}\Theta$ should be produced; but as this hydrate is not stable, protoxide results.

$$2\left(\begin{matrix}\mathrm{N}\Theta_2\\ \mathrm{Ag}\end{matrix}\right\}\Theta\Big) + 2\left(\begin{matrix}\mathrm{K}\\ \mathrm{H}\end{matrix}\right\}\Theta\Big) = 2\left(\begin{matrix}\mathrm{N}\Theta_2\\ \mathrm{K}\end{matrix}\right\}\Theta + \left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\Theta + \left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\Theta$$

Nitrate of silver. Hydrate of potassa. Nitrate of potassa. Protoxide of silver. Water.

Oxide of silver readily decomposes into oxygen and metallic silver when heated. It is a powerful basic anhydride, dissolving in the acids, and forming normal salts with them. Water dissolves it in the proportion of $\frac{1}{3000}$, sufficient to decompose the soluble haloid salts and the phosphates. By digesting oxide of silver with ammonia, an explosive compound is obtained, known as fulminating silver, the formula of which has not yet been determined with certainty. Some consider it to be a substance corresponding to the formula $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\mathrm{N}$, while others believe it to be a triargentic nitride $\left.\begin{matrix}\mathrm{Ag}\\ \mathrm{Ag}\\ \mathrm{Ag}\end{matrix}\right\}\mathrm{N}$.

Nitrate of Silver, $\left.\begin{matrix}\mathrm{N}\Theta_2\\ \mathrm{Ag}\end{matrix}\right\}\Theta$.—Nitrate of silver is prepared by dissolving silver in boiling nitric acid. If the silver employed be pure, the nitrate will be pure also; but if the silver contain copper the nitrate will be a mixture of nitrate of silver and nitrate of copper. The best process of purification in this case consists in evaporating till dry, and then fusing the residue, and keeping it in a state of fusion for some time. The nitrate of copper decomposes into oxide of copper and volatile products, and if the temperature is not too high, the greater portion of the nitrate of silver remains intact. A small portion of the mass is taken out from time to time and dissolved in water; after filtering, ammonia is added to the liquor. So long as this reagent produces a blue tint, there remains intact nitrate of copper; when the ammonia ceases to have any effect, the decomposition of that salt is complete. The whole mass, after being allowed to cool, is dissolved, and filtered to separate the oxide of copper, and then evaporated to the consistency of a thick syrup. The nitrate of silver crystallizes on the cooling of the liquor. Another process is to evaporate till dry, then to fuse the salt and to cast it upon porcelain, or in small wrought-iron moulds. Under the latter form it is employed in medicine, and known as lunar caustic.

Instead of decomposing the nitrate of copper in the manner we have described, it is usual, in laboratories, as being more simple, to treat the mixture of the two salts with a soluble chloride, which precipitates the silver alone as a chloride. This chloride, after being well washed and dried, is heated in a crucible to a white heat, carbonate of potassa and marine salt having been previously added. A button of very pure silver is then formed, which may be taken out of the crucible by breaking the latter after it has been allowed to cool. This button, dissolved in nitric acid, gives very pure nitrate of silver.

Nitrate of silver crystallizes in beautiful rhomboidal flakes, especially by evaporation from its acid solutions. Its crystals are transparent. When fused, it presents the aspect of a white mass of crystalline structure. As it is decomposed by heat, giving metallic silver, it becomes of a blackish colour after having been subjected to repeated fusions. When cast in the form of lunar caustic there always remain residues, which are melted a second or even a third time. These residues therefore assume the colour often possessed by lunar caustic.

The solution of nitrate of silver is decomposed by hydrogen, as it would be by a metal, such as zinc; nitric acid is formed, and the silver is deposited.

$$\underset{\text{Nitrate of silver.}}{2\left(\left.\begin{matrix}N\Theta_2\\Ag\end{matrix}\right\}\Theta\right)} + \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}} = \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Silver.}}{\left.\begin{matrix}Ag\\Ag\end{matrix}\right\}}$$

Nitrate of silver is decomposed by organic substances under the influence of light.

Distinctive Features of the Salts of Silver.—The soluble salts of silver are distinguished by the following features;—

1. They are always colourless when the elements of no coloured acid enter into their composition, and they are generally blackened by exposure to light.

2. Hydrochloric acid and the soluble chlorides produce in their solutions a white flocculent precipitate of chloride of silver which is not attacked by the acids, but which dissolves very readily in ammonia, cyanide of potassium, and hyposulphite of soda. This precipitate assumes a violet hue when exposed to the light.

3. The soluble arsenites and phosphates determine in them the formation of a light yellow precipitate of phosphate or arsenite of silver, soluble in ammonia and in acid liquors.

4. The arseniates produce in them a red precipitate of arseniate of silver.

5. Sulphuretted hydrogen gives with them a black precipitate of sulphide of silver, which is insoluble in hydrosulphate of ammonia, but which is readily converted into nitrate of silver by nitric acid.

6. The fixed alkalies give with the salts of silver a brown precipitate of oxide of silver. This precipitate when placed in contact with ammonia becomes black, and acquires explosive properties.

7. The soluble iodides convert the soluble salts of silver into iodide of silver, which is precipitated. This iodide is of a yellowish colour, easily affected by light, and nearly insoluble in ammonia; it is, however, readily soluble in hyposulphite of soda and cyanide of potassium. Boiling nitric acid decomposes it slowly, forming nitrate of silver, and liberating violet-coloured vapours of iodine.

Native Silver sometimes occurs in a state of almost chemical purity, but it is more frequently associated with some other metal or metals. Native silver is often found in connection with various argentiferous ores, and has sometimes been met with in masses of considerable size. It is found both crystallized and in arborescent and filiform shapes.

The alloys of silver and gold are exceedingly numerous, and although native gold has never been found free from silver, it is in some cases alloyed with that metal to such an extent, that the resulting compound can only be regarded as native silver containing traces of gold. Silver obtained from the treatment of ordinary argentiferous ores frequently contains gold, but generally speaking in small quantities only. In some districts, however, as at Virginia City in Nevada, one-third of the value of the bullion produced arises from the amount of gold which it contains.

Antimonial Silver.—Discrasite occurs in Baden, Suabia, Chili, and elsewhere; but seldom in sufficient quantities to possess great commercial value. Colour, silver white; composition, antimony 23, silver 77 per cent. Heated before the blow-pipe, gives off fumes of antimony.

Bismuth Silver.—A rare alloy of silver and bismuth, with a little copper and arsenic; occurs in the mine of San Antonio, near Copiapo, Chili. It contains 60 per cent. of silver.

Native Amalgam is found in the Palatinate, at Sala in Sweden, Almaden in Spain, and in various mines in Chili. It is frequently crystallized, of a silver-white colour, is brittle, and emits a grating sound when cut. There are two known varieties. The first is composed of silver 34·8, mercury 65·2, and the second of silver 26·25, mercury 73·75 per cent.

A silver amalgam of some commercial importance is found in the mines of Arqueros in Chili, and has been hence named Arquerite. It consists of silver 86·49, mercury 13·51 per cent.

Ores.—The ores of silver which occur in greatest abundance, and which are consequently the most important, are the following;—

Silver Glance.—Vitreous Sulphide of Silver.—This is the most important ore of silver, and contains, when pure, silver 87·04, sulphur 12·96 per cent. It is found in Europe in the German mines. It is also abundant in the mines of America.

Stephanite.—Brittle sulphide of silver is the ore of next greatest importance. This is a double sulphide of silver and antimony, containing, when pure, silver 70·4, antimony 14·0, and sulphur 15·6 per cent. It is found in nearly all the silver mines of Europe, and occurs abundantly in America, and particularly in the Comstock lode, Nevada.

Pyrargyrite.—Ruby Silver.—An important ore in the Mexican mines, as well as of those in the Reese River district in Nevada. It is composed of the same substances as stephanite, but in different proportions. When pure, its composition is, silver 58·98, antimony 23·46, and sulphur 17·56 per cent.

Chloride of Silver.—Horn Silver.—This ore is composed of silver 75·33, chlorine 24·67 per cent. It is found in most of the silver mines both of Europe and America, and occurs in greatest abundance near the outcrops of the veins. It fuses in the flame of a candle, giving off acrid fumes; and if moistened and rubbed with a piece of iron or zinc, becomes externally coated with a thin film of metallic silver. With a little carbonate of soda it is readily reduced before the blow-pipe, and affords a button of silver.

In addition to the foregoing, which yield the larger proportion of the total amount of silver annually produced, there are numerous other minerals containing this metal, but which, from their rarity, may be regarded rather in the light of mineralogical curiosities than as ores of silver. A large amount of silver is likewise extracted from galena, with which it is associated in the form of sulphide.

Few metals enter into a greater variety of natural combinations, or are found over a wider geological range, than silver. It is said to exist in minute traces in some organic bodies, and in the waters of the ocean. A certain amount of this metal invariably accompanies native gold, and it would be almost as difficult to find a specimen of galena from which traces of silver could not be extracted, as to meet with native gold entirely free from it.

The whole of the silver of commerce is derived from three sources;—

From silver ores proper, in which this metal predominates in value over those with which it is associated.

From refining the native alloys of gold and silver. And

From the desilverizing of lead, and the treatment of certain argentiferous copper ores.

Treatment of Silver Ores.—It has been found that the ores of silver, with the exception of argentiferous galenas, do not generally admit of mechanical concentration, and they are consequently, after careful selection, in most cases subjected to metallurgical treatment. The difficulty of treating ores of silver by mechanical means arises from the fact of the greater portion of this metal being finely disseminated in the veinstone in the form of various brittle sulphides, which, on the pulverization of the ores, become so finely divided as to float off in suspension in the water employed for concentration. It must be borne in mind that, even had the results obtained by mechanical preparation been more favourable than they have been generally found to be, the supply of water in the districts affording a great proportion of the ores of this description, is exceedingly limited, and that the inconvenience and expense attending the dilution of the argentiferous mineral by a large quantity of silicious and earthy matter is less than the cost and trouble that would be entailed by their concentration.

Patio Process.—The materials necessary for the reduction of the ores of silver by the patio process are magistral, common salt, and mercury; but in addition to these, sulphate of copper, precipitated copper, and copper and zinc amalgams are occasionally employed.

Magistral is manufactured from copper pyrites, or raw magistral, of which mines occur in many parts of Mexico.

The copper ore, when brought to the works, is first reduced to a coarse sand by dry stamping, and then ground to a fine powder in arrastres. The ground ore is removed from the arrastre to an enclosure, where the water with which it has been mixed during the process of grinding is allowed to evaporate; it is then left exposed for a long time to atmospheric influences, as it is generally believed to afford a larger proportion of sulphate of copper by roasting, if previously exposed for some months to the action of the air. The furnaces in which the calcination is effected have a double hearth, of which the roof is almost flat, with a fire-place at the side.

About 200 lbs. of ground ore, with which a few handfuls of salt have been previously mixed, are charged on each hearth. The heat is then gradually raised, and the ore kept constantly stirred during from six to eight hours, when the doors are closed, and the furnace allowed to cool. When sufficiently cold, the doors are again opened, and the charge raked through holes in the bottom of the furnace into arched recesses beneath, prepared for its reception. The percentage of sulphate of copper formed, from an ore of given tenure in copper, depends, to a great extent, on the skill of the workman, and the care bestowed on the operation.

When the ores treated contain either oxide or carbonate of copper, it is usual to add to them a certain amount of iron pyrites, which, by supplying sulphur, assists in their conversion into sulphates. The sulphate thus obtained, being in an anhydrous state, becomes heated on the absorption of water, and this circumstance is taken advantage of for the purpose of making a rough estimate of the quality of prepared magistral, and determining the proportion it will be necessary to employ.

The ores subjected to patio amalgamation differ somewhat in their composition; but the following analysis gives the average composition of ore from the district of La Luz, Guanaxuato;—

Sulphide of silver	0·15	Peroxide of manganese	3·54
„ iron	26·52	Carbonate of lime	4·18
„ lead	2·07	„ magnesia	0·96
„ arsenic	0·10	Silica	50·00
„ zinc	5·00	Moisture	6·10
Sulphate of iron	0·25		
„ lime	0·43		100·00

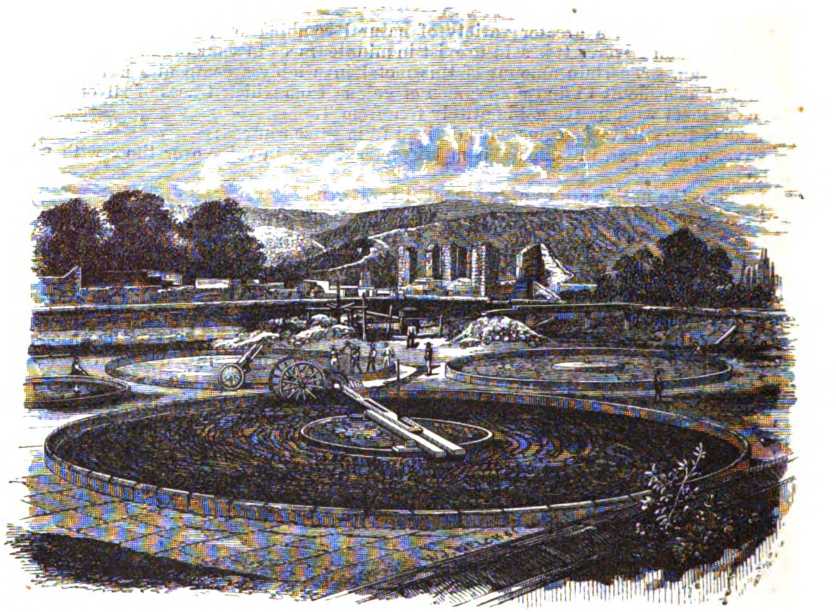
The ores to be subjected to the process of patio amalgamation are first crushed dry, to the state of coarse gravel in a stamping mill, and subsequently reduced by porphyrization with mercury in the arrastre to the necessary degree of fine division.

As the operation of grinding progresses, the amalgam by degrees accumulates in the crevices in the bottom of the arrastre. The amalgam is usually removed from the arrastres every three months; but in some instances they are cleaned up at even longer intervals. At the expiration of twenty-four hours, when the grinding is completed, slime is baled out into a barrel, in which it is

removed to reservoirs, formed in masonry, from which a portion of the water becomes evaporated by exposure to the sun and air, and leaves the mass in a fit condition for subsequent treatment in the patio.

The patio is a large courtyard, generally paved with flagstones, of which the joints are carefully cemented, in order to prevent the loss of mercury which would otherwise take place. This flooring has a slight inclination given to it, in order that any water falling on it may the more readily run off. In some cases, however, a wooden flooring is employed instead of a stone one. Fig. 6900 represents the patio at Guanaxuato.

6900.



The ground slimes, on their removal from the arrastres, are deposited, in an almost liquid state, in walled receivers, where a portion of the water is removed by evaporation, and where it is allowed to accumulate until there is a sufficient quantity to form a heap. When the amount of slimes necessary for a heap has been collected in the receiver, it is carried out into an enclosure formed on the patio, about 30 ft. in diameter, generally made by laying on each other square beams of wood, kept in their places by large stones, and made tight by filling the joints either with clay or horse-dung. Into this the slime is introduced, until it forms a layer of about a foot in thickness, and is allowed to remain until, by the evaporation of the water, it has gained the consistency of a rather thin mud. From 3 to 5 per cent. of salt is added, in accordance with its quality and the nature of the ores under treatment. When the salt has been added to the heap or torta, it receives the first treading by mules, after which it is allowed to stand until the following day, when the whole of the salt will be found in a state of solution, and thoroughly mixed with the slimes composing the heap.

The day after the salt has been thus mixed with the slimes, the addition of magistral and mercury takes place. For this purpose the torta is, if necessary, brought to the proper consistency by the addition of water, and the magistral thrown evenly over its surface by means of wooden shovels. The proportion of this reagent to be added varies, to a certain extent, in accordance with its richness in sulphate of copper; but in the case of employing magistral of the usual strength, something less than 1 per cent. is generally found sufficient. As soon as the magistral has been spread over the surface of the heap, it is again trodden by mules for about an hour, when the mercury necessary for the completion of the operation is generally added, the quantity required being from 3¼ to 4 lbs. for every mark of silver supposed to be contained in the heap. The introduction of mercury is effected by making it run through a linen cloth in such a way that its particles may be divided in the state of minute globules. After the addition of the mercury, the heap is again trodden for about four hours, in order to effect its intimate mixture throughout the whole mass. When crystallized sulphate of copper is employed in lieu of magistral, from 7 to 9 lbs. are added for each ton of ore contained in the heap.

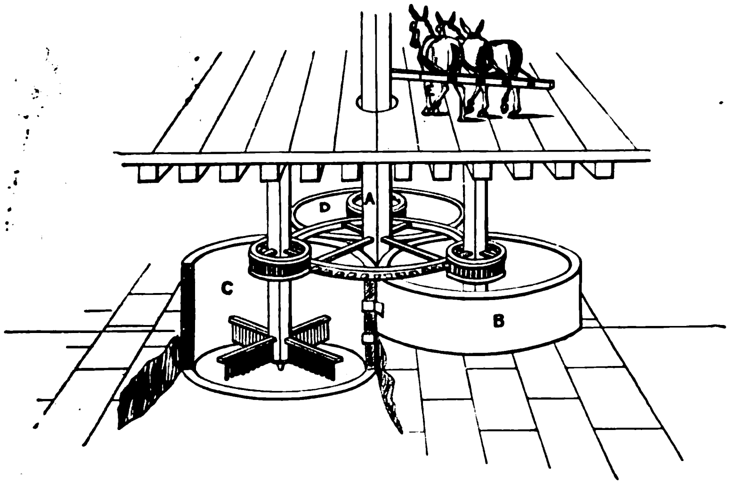
The treading of a torta has the effect of stimulating the action of the magistral, and is repeated every alternate day as often as the samples indicate a necessity for doing so. Formerly, the mercury was not all introduced at once. It is, however, now usual to add all the mercury immediately after the introduction of magistral.

The treading tortas or heaps is effected by means of mules or horses, the former being most frequently employed, and is repeated every alternate day until the operation is completed; in some cases they are made to drag behind them a framework on wheels, which acts in the same way as the ordinary mortar mill. When this is employed, it is attached to a long wooden arm revolving

on a spindle in the centre of the torta, and in order to allow of the radius being gradually diminished, the arm is provided with slots, in which the central pin readily traverses. In addition to the treading, each heap is turned over twice a week by means of wooden shovels.

The washing apparatus consists of three circular tanks B, C, and D, Fig. 6901, built close

6901.



together in a circle, and constructed of stone slabs carefully cemented. The depth of each of these tanks is 5 ft. 4 in., and its diameter 9 ft. 6 in. They are made to communicate with each other by means of an oblong opening 8 in. in height and 10 in. in width; of which the first is placed at a height of 8 in., and the other at a distance of 30 in. from the bottom of the tanks. In addition to these, the last tank is provided with two separate discharge-holes; the first at a height of 6 in. from the bottom, and the other, which is only opened for the purpose of cleaning up, is situated close to the bottom. The diameter of the upper opening is about 4 in., and that of the lower 1 in.

In the middle of each tank is an upright wooden shaft carrying four arms furnished with wooden teeth acting as agitators, the whole being set in motion by a central shaft A provided with a spur-wheel working in pinions on the tank-shafts.

The pinions giving motion to the agitators in the second and third tanks are a little larger than that working the stirrer in the first, and consequently their motion is somewhat slower.

Before being washed, the torta is first divided into several parcels, each of which is softened by the addition of water and subsequent treading, and then carried to the washing house in large bateas, dusted on the inside with dry horse-dung in order to prevent loss.

When the washings of samples taken from the tanks afford only minute metallic traces, the plug at some distance above the bottom of the discharge-tank D is removed for the purpose of discharging the slimes; and as soon as they have been run off the plug is replaced, and the operation continued until the whole has been washed up.

In addition to the amalgam which remains in the bottom of the tank, there is also a considerable quantity of the heavier constituents of the ore treated. This residue is removed in wooden bowls to another tank, and thrown into large bowls or bateas. The person using the batea leans over the side of the tank, and with one hand on each side of the bowl, gives to it the peculiar washing motion, taking up a small quantity of water, which, after circulating round the edges of the vessel, is finally discharged, carrying with it a certain portion of the residue. The deposit of finely-divided mineral remaining with the amalgam in the washing apparatus, and from the washing in bateas, is subsequently reground in arrastres. By this means it is made to yield a certain quantity of amalgam rich in gold, but is not generally a second time subjected to patio amalgamation.

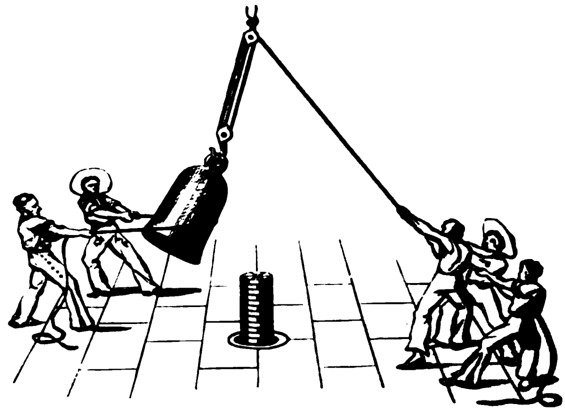
The amalgam thus obtained is carried to the mercury house, where it is deposited in a large stone trough; and as soon as the whole amount produced by a heap has been collected, a large quantity of pure mercury, together with a little water, is added. The mass is now well stirred by hand, for the purpose of causing the separation of impurities which gradually come to the surface, and which are from time to time wiped off by means of a woollen cloth. A small quantity of clean water is added after each removal of the impurities, and the operation repeated until the surface of the amalgam presents a bright uniform appearance.

When the amalgam has been purified from the last adhering particles of mineral, by wiping with flannel, it is filtered through a cone-shaped bag, or strainer, Fig. 6902, of which the upper portion is covered with leather, while the lower consists of strong, closely-woven canvas. This is hung by chains or cords from a stout beam, and when the mixture of mercury and amalgam is introduced, its weight causes a large portion of the quicksilver to escape through the meshes of the sail-cloth in a liquid form, and to fall into a vessel placed beneath it for that purpose. The amalgam finally assumes the appearance of white sand. This amalgam usually contains mercury to the amount of from five to five and a half times the weight of silver present.

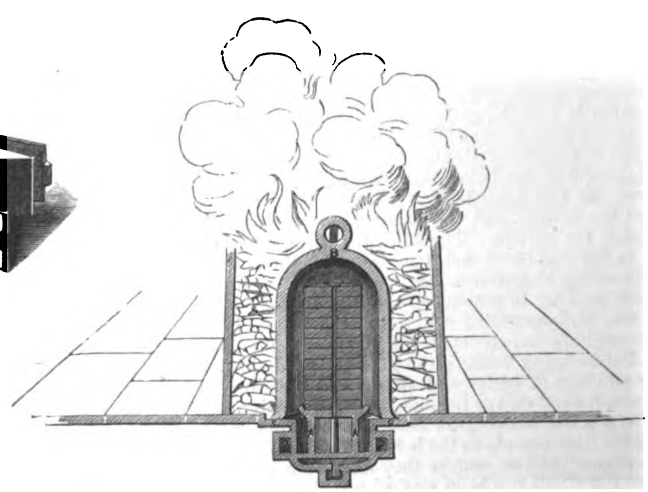
The filtration of a charge usually occupies about two hours; and when the mercury has ceased to drip from the bottom of the bag, the strainer is emptied on a table covered with leather, and the amalgam beaten into triangular bricks in iron moulds having the form shown, Fig. 6903.

6902.

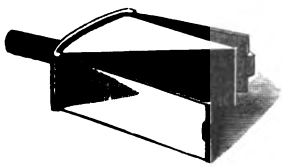
6904.



6905.



6903.



The retorting is conducted by the aid of a large iron or copper bell, which is placed over the amalgam, and around which is kindled a charcoal fire. A circular tank of masonry is constructed below the floor of the burning-house, through which a stream of water is constantly flowing, and in this is placed an iron tripod, covered by a round plate, having a hole in its centre for the escape of mercury. On this plate are piled the bricks of silver, to such a height as to reach to within a short distance of the top of the bell, which, when placed over them, leaves a space of about an inch between its sides and the column of amalgam. When thus arranged, the bell or capellina is lowered over it, and the bottom secured, either by lute or a water-joint, constantly supplied by means of a pipe Unburnt bricks are now built around the arrangement in the form of a hollow wall, leaving an annular space between them and the bell, of about 8 in. width. This is filled with charcoal, which is ignited, and as the temperature increases, the mercury becomes volatilized, and, passing into the chamber below the floor, is condensed, collects in a liquid form, and escapes by an iron pipe into a proper receptacle. The fire is thus kept up during about fifteen hours; after which the apparatus is allowed to cool, and, when sufficiently cold, the bell is removed, either by a windlass or by means of simple blocks, as in Fig. 6904.

This silver, which is found to have assumed a porous structure, and a beautiful frosted appearance, is placed in leathern bags for removal to the smelting house, where it is assayed, and run into bars. The silver obtained by the patio process of amalgamation is in most cases very nearly pure, being generally above 990 fine.

In some localities, the arrangements for retorting by the capellina are slightly varied from those above described, as Fig. 6905, in which the amalgam is supported beneath the bell B, on a stand A, enclosed in a cast-iron vessel C, kept cool by means of a current of water constantly flowing beneath the bottom, and through the annular cavity D. The condensed mercury escapes, as soon as

deposited, by means of a wrought-iron pipe, into a proper receiving vessel. In some cases the charcoal is retained in its place by means of a circular iron grating.

The interior measurements of the bell are usually as follow;—height, 3 ft.; diameter, 18 in.; thickness of metal, 1½ in. The charge of amalgam is about 2000 lbs., affording about 400 lbs. of silver; the consumption of charcoal a charge is 500 lbs.

The loss of silver by this process of amalgamation is considerable, but varies in different localities, in accordance with the nature of the ores operated on, and the degree of fineness to which they are reduced by grinding. The loss of mercury is generally equivalent to the weight of silver obtained. The results of assays made during a year on ores containing a considerable quantity of galena, pyrites, and blende, as compared with those actually obtained from the patio, showed a deficit equal to 28 per cent. of the assay produce.

After the discovery of silver mines in Nevada, it became evident that none of the processes employed in other countries for the reduction of silver ores could be rendered available for the treatment of those forming the main deposits. The pan, or Washoe process, so called from the district where it was first employed, was therefore introduced. The following description, although confined to the Comstock ores, gives a fair general outline of the process.

The ores of the Comstock lode consist chiefly of various sulphuretted forms of silver, native silver, and gold, finely, almost imperceptibly, disseminated through a gangue of quartz. With these are associated a few other accessory minerals in inconsiderable proportions.

For metallurgical treatment they formerly were, and to some extent still are, divided into three classes. The basis of this assortment is arbitrary. The chief object of the classification is to separate those ores whose mineral composition and, more especially, whose high value demand a very exact and careful treatment in order to obtain the highest possible percentage of their precious contents from those of lower grade, which must be treated by less expensive methods.

The first class usually embraces those ores whose assay value exceeds $150, or in some cases, $100, a ton. The second class, where distinguished at all, is usually designed to include ores whose assay value ranges between $90 and $150 a ton. The third class embraces all workable ore of lower grade than the foregoing, the average assay value varying considerably in different mines.

In many of the mines the proportion of the second-class ore is so small, or the character of the ore so uniform, that no such distinction is made, the whole product being worked without assortment. About 25 to 30 per cent. of the whole value contained in these ores is gold, the remainder is silver. In the bullion produced the relative proportion of the gold is a little higher, as it is more easily saved than the silver.

The silver of the first-class ores is intimately combined with sulphur, zinc, lead, iron, and other base metals, which render the extraction of the silver difficult. They cannot be profitably treated by the simple methods to which the more docile ores of the second and third classes are subjected. but are crushed dry, roasted with salt in reverberatory furnaces, and then amalgamated in barrels by the Freiberg process. The ores of the second and third classes are treated by the pan process.

The ore to be treated by the ordinary Washoe process is delivered from the mine to the mill in pieces varying in size from fine particles to those as large as a man can lift. It needs first to be crushed to a fine condition. This operation is performed by a battery or stamps similar to that described at p. 272. The larger pieces of ore are first broken to a suitable size for feeding the stamps, either by a sledge or a mechanical rock-breaker, Blake's machine being in general use for this purpose.

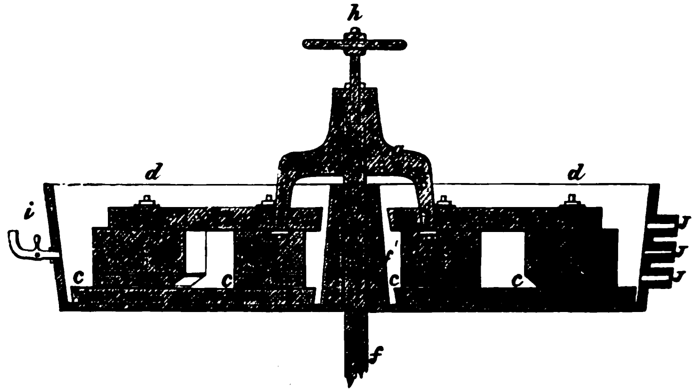
The screens through which the crushed material is discharged from the mortar are either of brass wire-cloth, having thirty-five or forty meshes to the lineal inch, or more frequently of Russia sheet iron, perforated with fine holes. Screens of the latter sort, in general use, are known as Nos. 5 or 6. In the last named the hole has a diameter of $\frac{1}{40}$ of an inch.

In former years the amalgamation of the precious metals of the ore with quicksilver was carried on in the mortar. This feature of the process has, however, been given up in the mills of the Washoe district. The stuff, being discharged from the battery, is conveyed in troughs by means of the flowing water to settling tanks, placed in front of the batteries. These tanks are usually built of plank, are 3 or 4 ft. deep by 5 or 6 or more feet square, and are so arranged as to have communication with each other near the top, so that the stream of water carrying the crushed ore in suspension, having filled one tank may pass into the next, and so on through several, depositing the material and not finally leaving the tanks until it has become tolerably clear. The number of tanks must be sufficient to allow of a certain portion being emptied; while others are receiving their supply, and the conveying troughs are provided with gates so arranged that the stream can be admitted to one portion of the tanks and shut off from the other at pleasure. The stream, having deposited in these tanks the bulk of the material, is still charged with slimes, or rock reduced to an impalpably fine condition, which is only settled by a slow process. For this purpose the stream is sometimes permitted to pass through other large settling tanks, or to slowly deposit its charge in a pond or dam outside the mill. These slimes form a variable and in some mills a large percentage of the whole amount crushed; in some instances more than 10 per cent. When one or more of the settling tanks in the mills have been filled the stream is diverted from such to others that have been emptied, and the full ones are in their turns cleaned out, the sand or crushed ore being then subjected to the grinding and amalgamating process of the pan.

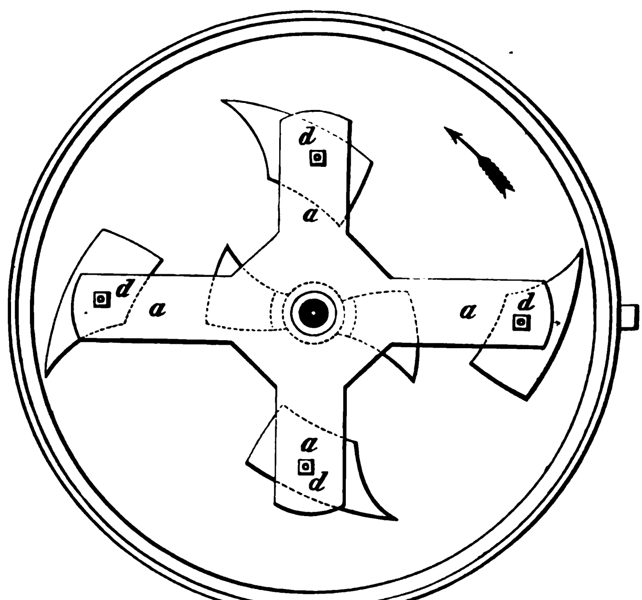
Modifications of the amalgamating pans employed in the reduction works of Nevada are almost endless. There is, however, a simple form of apparatus usually known as the common pan, with which results can, by careful working, be obtained almost as good as from those of more complicated construction. The common pan, Figs. 6906, 6907, is a round wooden or cast-iron tub, 6 ft. in diameter, and about 2 ft. in depth, with a flat bottom. A false bottom of 1½-in. iron is inserted into this, and a hollow pillar in the centre admits the passage of an upright shaft, which is generally worked by gearing beneath the pan, capable of communicating to it from fifteen to twenty revolutions a minute. To the wooden arms *a* are attached the blocks *b*, also of wood, to which are fastened the

iron shoes c, by means of the bolts d, passing up through the arms. Each shoe has also an iron pin, about an inch in length, which fits into the wooden block and keeps the iron facing steadily in its

6906.



6907.

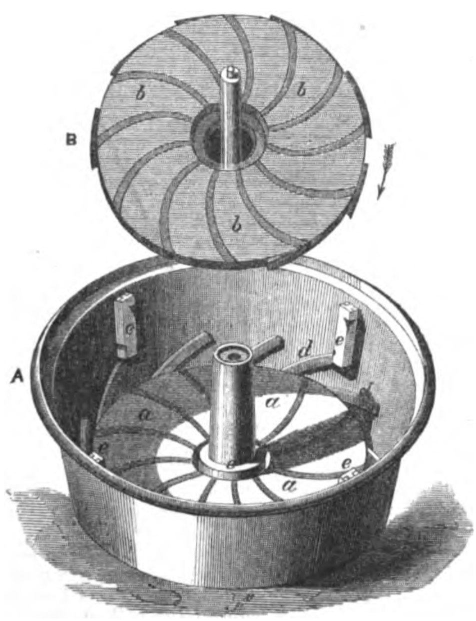


place. On the shaft f, passing through the central pillar f', is the yoke g, which, being fitted with a sliding key, can be raised by means of the screw h; and the ends of the yoke itself being attached to the wooden cross arms, the mullers will be raised at the same time. Steam is introduced into the pulp by the pipe i, the discharge being effected by means of the apertures J. The false bottom is made 1 in. less in diameter than the bottom of the pan itself, and has an aperture in the centre an inch larger in diameter than the base of the pillar, in which the vertical shaft works. To fasten the bottom in its place, and prevent the mercury from finding its way under it, strips of cloth, about 2 in. in width, are lapped around the edge of the false bottom, as well as applied against the sides of the pan. A little iron cement is then poured in, and the bottom secured in its place by means of well-dried wooden wedges tightly driven between the two layers of cloth. These wedges, which are driven quite close to each other, must be somewhat shorter than the thickness of the false bottom; thus leaving a space above them which is subsequently covered with a paste of iron cement, that is allowed to set before using the apparatus. About 1 horse-power is required to work this pan, which will amalgamate from 1½ to 2 tons of ore in the course of twenty-four hours.

A very good, but more complicated pan is Wheeler's, represented in Fig. 6908, A being the pan, with the dies a in their several places; whilst B is the rotating muller, fitted with its shoes b, removed from the pan, and turned bottom upwards. The upper muller is driven by means of a

hollow cone, which passes over the central pillar, and is connected with the vertical shaft by means of a sliding key.

6908.



The distance between the mullers is regulated by a screw, fitted with a hand-wheel. The shoes *b* are secured to the upper muller, either by bolts and nuts, or more frequently by projections passing through inclined oblong holes in the rotating plate, to which they are firmly secured by means of wooden wedges. The dies *a* are laid on the bottom of the pan, and kept in their places by the ring *c* in the centre, and on the sides by the inclined ledges *d*, under which their ends are wedged. The dies, like the shoes, are 1 in. thick, and bevelled on the edges in the same direction; so that, when put together, grooves are formed between them, as shown in the drawing. On the upper side of the outer edge of the muller are inclined ledges, which in connection with those, *d*, cast on the pan, create an upward current in the pulp; whilst guide-plates, which slide into grooves at *e*, convey it towards the centre. This pan stands on a cast-iron framing, and is driven by mitre-wheels from beneath.

From the dies and bottom not being cast perfectly true, the grinding surfaces are often, at first, a little uneven, and consequently the grinding planes should not at once be brought into too close contact.

The runner of these pans requires to be lifted at least once a week for the purpose of removing the amalgam which accumulates around the central pillar, and thus prevents the pulp from passing freely between the grinding surfaces. This pan is generally made 4 ft. in diameter at bottom, and requires from 2½ to 3 horse-power to work it efficiently. It usually makes about sixty revolutions a minute.

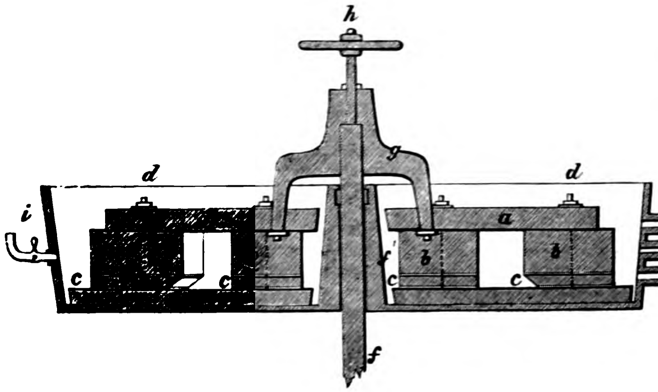
The operation of the pan consists in the further reduction or grinding of the stamped rock to a fine pulp and in the extraction of the precious metals by amalgamation with quicksilver. The quantity of ore with which a pan is charged for a single operation varies from 600 or 800 to 4000 or 5000 lbs., according to the size of the pan. The ordinary charge of pans most generally in use is 1200 to 1500 lbs.

In charging the pan the muller is raised a little from the bottom, so as to revolve freely at first. Water is supplied by a hose-pipe, and at the same time the sand is thrown into the pan with a shovel. Steam is admitted, either to the steam-chamber, in the bottom of the pan, or directly into the pulp. In the former case the temperature can hardly be raised as high as in the latter; but, on the other hand, when steam is introduced directly care is necessary to avoid reducing too much the consistency of the pulp by the water of condensation. The pulp should be sufficiently liquid to be kept in free circulation, but thick enough to carry in suspension, throughout its entire mass, the finely-divided globules of quicksilver. In some mills both methods of heating are employed in the same pans, the temperature being first raised with each charge by live steam, and afterward sustained by admitting steam to the chamber only. Some pans are covered with wooden covers to assist in retaining the heat. When properly managed the temperature may be kept at or near 200° Fahr. When, in the use of live steam, the pulp becomes too thin, the supply of steam is cut off, the covers removed, and the pulp allowed to thicken by the evaporation of the water. The steam in the chamber may keep the temperature up to the desired point in the meantime. Another advantage of the steam-chamber is that the exhaust steam from the engine may be used in it, while for use in the pulp it is better and customary to take steam directly from the boilers, because that which comes from the cylinder of the engine is charged with oil and is injurious to amalgamation. The muller is gradually lowered after the commencement of the grinding operation, and is allowed to make about sixty or seventy revolutions a minute. In the course of an hour or two the sand should be reduced to a fine pulpy condition. When this has been accomplished, and occasionally at an earlier stage of the operation, a supply of quicksilver is introduced into the pan, the muller slightly raised from the bottom to avoid too great friction, which would act to the disadvantage of the quicksilver, and the action continued for two hours longer, during which the amalgamation is in progress. The quicksilver is supplied by pressing it through canvas, so as to scatter it upon the pulp in a finely-divided condition. The quantity varies greatly in different mills, the ordinary supply being about 60 or 70 lbs. to a charge of ore consisting of 1200 or 1500 lbs. In some mills a quantity, varying from 75 to 200 or even 300 lbs., is put into a pan when starting up after a clean-up, and subsequently a regular addition of 50 or 60 lbs. made with each charge.

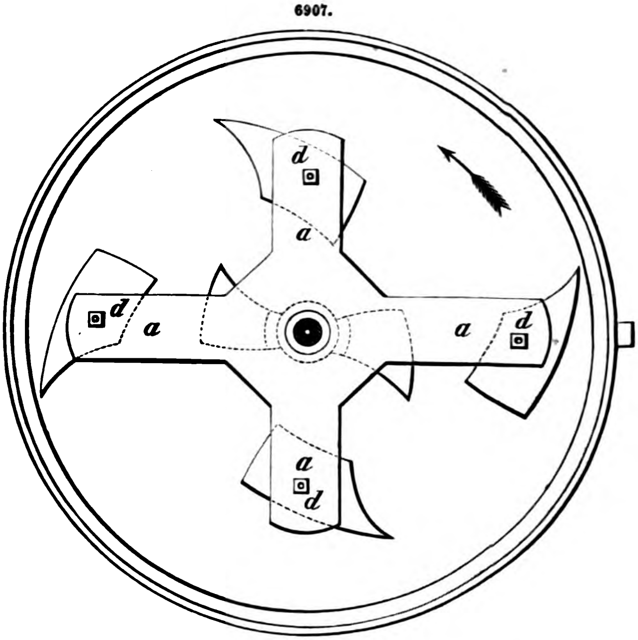
To promote amalgamation it is the general custom to add to the charge, either at or soon after the beginning of the grinding, or at the time of supplying the quicksilver, various materials generally described as chemicals, and usually consisting at the present day of sulphate of copper and

iron shoes *c*, by means of the bolts *d*, passing up through the arms. Each shoe has also an iron pin, about an inch in length, which fits into the wooden block and keeps the iron facing steadily in its

6906.



6907.

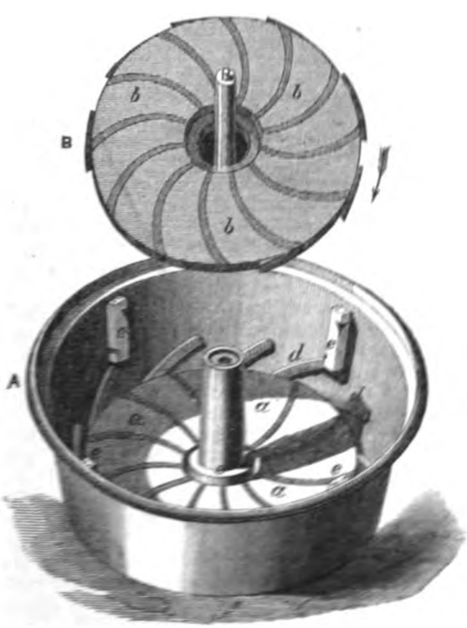


place. On the shaft *f*, passing through the central pillar *f'*, is the yoke *g*, which, being fitted with a sliding key, can be raised by means of the screw *h*; and the ends of the yoke itself being attached to the wooden cross arms, the mullers will be raised at the same time. Steam is introduced into the pulp by the pipe *i*, the discharge being effected by means of the apertures J. The false bottom is made 1 in. less in diameter than the bottom of the pan itself, and has an aperture in the centre an inch larger in diameter than the base of the pillar, in which the vertical shaft works. To fasten the bottom in its place, and prevent the mercury from finding its way under it, strips of cloth, about 2 in. in width, are lapped around the edge of the false bottom, as well as applied against the sides of the pan. A little iron cement is then poured in, and the bottom secured in its [illegible] well-dried wooden wedges tightly driven between the two layers of cloth. [illegible] driven quite close to each other, must be somewhat shorter than the [illegible] thus leaving a space above them which is subsequently covered [illegible] allowed to set before using the apparatus. About 1 horse-[illegible] which will amalgamate from 1½ to 2 tons of ore in the cour[illegible]

A very good but more complicated pan is Wheeler's [illegible] with the dies *a* in their several places; whilst B [illegible] removed from the pan, and turned bottom upwar[illegible]

hollow cone, which passes over the central pillar, and is connected with the vertical shaft by means of a sliding key.

6908.



The distance between the mullers is regulated by a screw, fitted with a hand-wheel. The shoes *b* are secured to the upper muller, either by bolts and nuts, or more frequently by projections passing through inclined oblong holes in the rotating plate, to which they are firmly secured by means of wooden wedges. The dies *a* are laid on the bottom of the pan, and kept in their places by the ring *c* in the centre, and on the sides by the inclined ledges *d*, under which their ends are wedged. The dies, like the shoes, are 1 in. thick, and bevelled on the edges in the same direction; so that, when put together, grooves are formed between them, as shown in the drawing. On the upper side of the outer edge of the muller are inclined ledges, which in connection with those, *d*, cast on the pan, create an upward current in the pulp; whilst guide-plates, which slide into grooves at *e*, convey it towards the centre. This pan stands on a cast-iron framing, and is driven by mitre-wheels from beneath.

From the dies and bottom not being cast perfectly true, the grinding surfaces are often, at first, a little uneven, and consequently the grinding planes should not at once be brought into too close contact.

The runner of these pans requires to be lifted at least once a week for the purpose of removing the amalgam which accumulates around the central pillar, and thus prevents the pulp from passing freely between the grinding surfaces. This pan is generally made 4 ft. in diameter at bottom, and requires from 2½ to 3 horse-power to work it efficiently. It usually makes about sixty revolutions a minute.

The operation of the pan consists in the further reduction or grinding of the stamped rock to a fine pulp and in the extraction of the precious metals by amalgamation with quicksilver. The quantity of ore with which a pan is charged for a single operation varies from [illegible] to [illegible] or 5000 lbs., according to the size of the pan. The ordinary charge of pans most generally in use is 1200 to 1500 lbs.

In charging the pan the muller is raised a little from the bottom, so as to revolve freely at first. Water is supplied by a hose-pipe, and at the same time the sand is thrown into the pan with a shovel. Steam is admitted, either to the steam-chamber, in the bottom of the pan, or directly into the pulp. In the former case the temperature can hardly be raised as high as in the latter; but, on the other hand, when steam is introduced directly care is necessary to avoid reducing too much the consistency of the pulp by the water of condensation. The pulp should be sufficiently liquid to be kept in free circulation, but thick enough to carry in suspension, throughout its entire mass, the finely-divided globules of quicksilver. In some mills both methods of heating are employed in the same pans, the temperature being first raised with each charge by live steam, and afterwards maintained by admitting steam to the chamber only. Some pans are covered with wooden covers to assist in retaining the heat. When properly managed the temperature may be kept at or near 200° Fahr. When, in the use of live steam, the pulp becomes too thin, the supply of steam is cut off, the covers removed, and the pulp allowed to thicken by the evaporation of the water. The steam in the chamber may keep the temperature up to the desired point in the meantime. Another advantage of the steam-chamber is that the exhaust steam from the engine may be used in it; while for use in the pulp it is better and customary to take steam directly from the boilers, because that which comes from the cylinder of the en[illegible] with oil and is injurious to amalgamation. The muller is gradually lowered after [illegible] to make about sixty or seventy revolu[illegible] be reduced to a fine pulpy conditio[illegible] earlier stage of th[illegible] [illegible]

salt. The quantity used varies from a quarter or half a pound to three or four pounds to each charge of ore; the two substances being employed in very variable proportions in different mills.

Two hours having been devoted to the grinding, and two or three more to amalgamation, the pan is discharged, and its contents received by a settler or separator. The pan being emptied and partly washed out by the stream of water, is again charged with a fresh quantity of sand, and the grinding operation is resumed.

Settlers or separators, like the pans, differ somewhat in details of construction, but they usually are round tubs of iron or of wood with cast-iron bottoms, resembling the pans in general features, but larger in diameter.

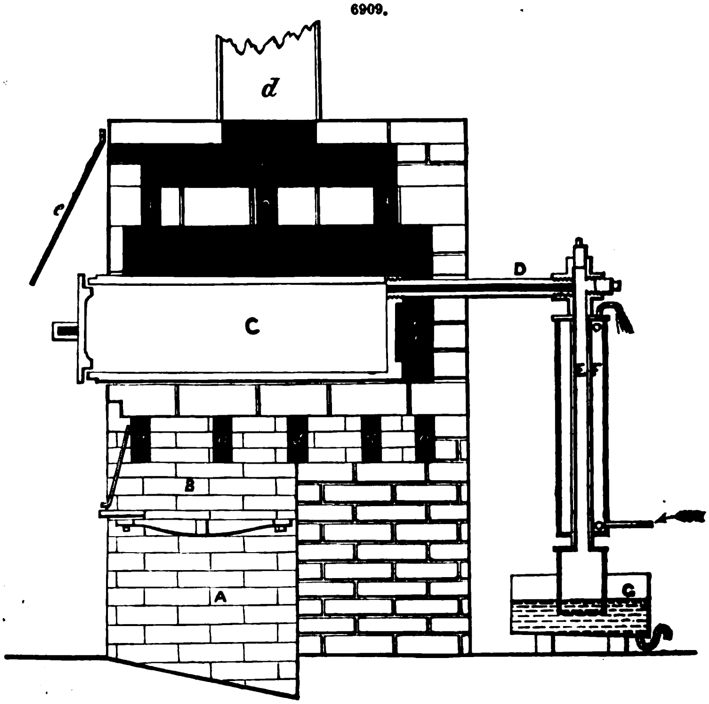
In some mills, at a stated hour of each day, the quicksilver coming from the settlers is strained and the amalgam extracted; in others, as the quicksilver thickens or becomes sluggish by the accumulation of amalgam, it is diluted by the addition of fresh quicksilver, and the straining of the amalgam is only made once in several days.

From time to time the pans and settlers must be stopped and cleaned. For this purpose the mullers must be raised, the shoes and dies removed from their places, and all the ironwork of the pans and settlers carefully scraped with a knife, to remove and collect the hard amalgam which attaches itself to such surfaces. In many cases one-fourth or even a greater proportion of the total product of amalgam is obtained in this way.

The amalgam, having been strained in bags similar to Fig. 6902, and forcibly pressed, to expel as much of the fluid quicksilver as possible, is then subjected to the process of sublimation in a retort about 12 in. in diameter and 3 ft. long, mounted on an arch of fire-brick, and placed within another arch, from the crown of which the smoke is carried off to the chimney. The retort is fitted with a stout cover, carefully adjusted like the stopper of a coal-gas retort. From the upper part of the end a 2-in. iron pipe carries off the volatile matters. This is so fitted to the downcast pipe, 4 ft. in length, that, by T-pieces and stoppers, every facility is afforded for cleaning out the pipes. The downcast pipe is so fitted within another pipe 3½ to 4 in. in diameter, as to constitute a Liebig's condenser, into the bottom of which cold water is supplied; the heated water flowing off from the top. The downcast pipe opens into a small bottomless chamber, immersed sufficiently low in a tank of water to keep it air-tight, but in such a manner as to prevent accidents from the absorption of water into the heated retort.

This retort is provided with several cast-iron semicircular trays, which slide easily in and out; these are divided into two parts by a transverse partition. Before the weighed charge of amalgam is put into the tray, it is coated with milk of lime, or a thin wash of clay, and not unfrequently a sheet of paper is also placed over the bottom. By these precautions the retorted amalgam is prevented from adhering to the iron, and much trouble avoided. The charge having been placed in the retort, the cover is carefully luted with a mixture of clay and wood-ashes, made up into a thin paste. The fire is then lighted, and the heat slowly and steadily raised, until the retort is of a bright red

6909.

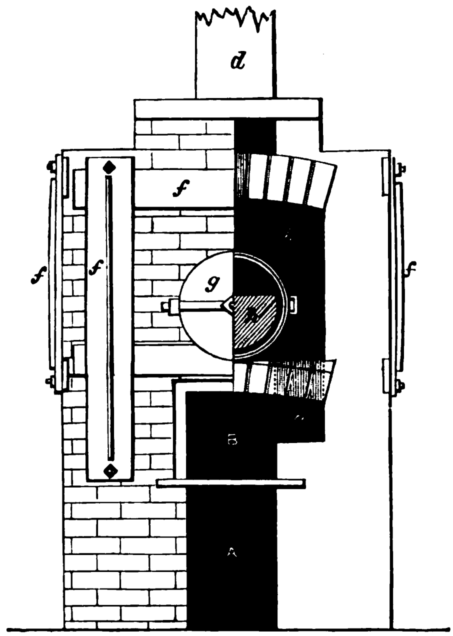


colour, and is so maintained until the mercury ceases to distil over. The retort is now allowed to cool gradually down, and when cold the retorted silver is withdrawn and weighed, as is also the

mercury obtained, as a precaution against any possible loss of quicksilver from hidden leaks in the retort. About one-sixth of the charge usually remains, or 200 lbs. of crude bullion from 1200 lbs. of amalgam. The retorted amalgam is broken up, melted in plumbago crucibles, and cast into bars or ingots of bullion of from 1000 to 1500 oz. each. These are assayed and valued, the value being marked on the bars, which are then ready for the market. The quality or fineness is marked in thousandths, thus—gold 24, silver 841, making together 865 thousandths; leaving 135 parts in a thousand, which principally consist of copper; but no notice is taken of this, as it is of no money value in the sale of the bar.

The retort employed at the mills near Virginia for the distillation of silver amalgam is represented, Figs. 6909, 6910, of which the second is partially in section, and the first is a longitudinal section.

6910.



The ash-pit A is beneath the fire-place B, which communicates, by means of flues *a*, with a chamber *b*, enclosing the cast-iron retort C, from which the products of combustion are conveyed by the flues 1, 2, 3, through the arched cavity *c*, to the chimney *d*.

By dampers covering these flues the draught may be controlled so as to heat the retort according to the requirements of the case. The pipe D carries the vaporized mercury to the vertical pipe E, in which it is condensed by the action of a stream of cold water passing upward from the bottom through the Liebig's condenser F. The condensed mercury collects in the reservoir G, from which it is drawn off into bottles through a bent tube at the bottom. Any vapours escaping from the retort-door are conveyed into the flues by the hood *e*, of sheet iron. The arrangement of the cover of the retort is shown at *g*, and a portion of the semi-cylindrical tray, used for charging the retort, at *h*; the position of the iron plates and braces for binding the brickwork is represented by the letters *f*.

The pulp, after passing from the settlers, in which, as before described, the quicksilver and amalgam are separated from it, is variously treated in different mills. Frequently the whole mass is allowed to pass through agitators, tubs, or vats of various devices, for the purpose of saving some of the quicksilver and amalgam that are unavoidably carried off with it from the settler. In some mills various kinds of concentrators are employed for a similar purpose, and to obtain the heavy undecomposed sulphurets in concentrated form; in other cases, where there is water sufficient and the lay of the land favourable, blanket-tables are constructed outside the mill, over which the stream of tailings is allowed to run, and a portion of their valuable contents caught in blankets; and, at convenient points, dams are constructed for the accumulation of tailings, which, after months of exposure to the influences of the weather, may be again worked over with profit.

The ordinary working result obtained by treating the ore as above described in the pan and settler varies between 65 and 75 per cent. of the assay value, which, by subsequent treatment, is increased sometimes to 85 or 90 per cent.

Barrel Amalgamation.—The combinations in which the gold and silver exist in the first-class Comstock ores unfit them for profitable treatment in the simple grinding and amalgamating process just described.

The method of treatment to which the ore is subjected, therefore, is similar to the Freiberg barrel process, and consists of drying, crushing by stamps without the use of water, roasting with salt, amalgamation in revolving barrels, and the separation of the gold and silver from the quicksilver by the method of retorting.

The drying kiln at the Savage mine is formed of a series of flues, covered by a cast-iron floor, on which the ore, already reduced to a size suitable for stamping, is spread. The surface for the reception of the ore is about 8 ft. wide by 12 ft. long. The iron is cast in sections or plates, 8 ft. long by 3 ft. wide, with a strengthening rib on the under side. The base of the kiln is brickwork, and the flues are about 8 in. deep. They are covered by the iron plates. At one end of the kiln is a fire-place, and at the other a stack, so that the heat passes from one end to the other under the iron cover or floor, on which the ore is spread to a depth of 4 or 5 in. The ore is constantly raked and turned until quite dry.

When the kiln is conveniently placed, as in some similar establishments in Eastern Nevada, the heat from the roasting furnaces, on its way to the stack, passes through the flues, saving a special firing. In the present instance there are three kilns, able to dry about 25 tons a day, consuming in all about a half cord of wood in twenty-four hours, and requiring one man's attention to keep up fires and rake over the ore.

For crushing the rock, after drying, there are twenty stamps, arranged in batteries of four, weighing about 600 lbs. each, dropping 8 or 9 in. about sixty-five times a minute. The foundations

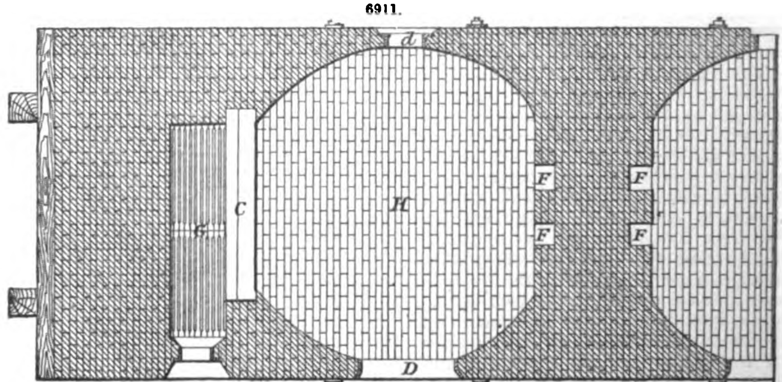
and battery-frame are not essentially different from those in wet-crushing batteries. The mortars differ from the high ones used for wet-crushing, consisting of a bed-piece, with sides and ends that are only high enough to provide the means of bolting the iron casting to the woodwork of the battery-frame, attaching the screen-frames.

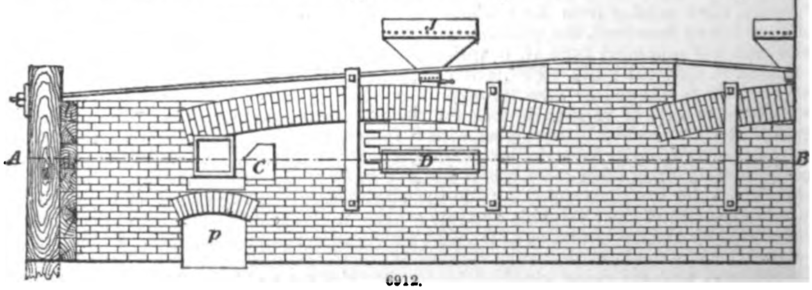
The dies are flat, circular pieces of cast iron, that fit into recesses in the bottom of the mortar. Each die has two lugs or projections on its periphery, which, being dropped into a groove in the bottom of the mortar, may then be revolved 90°, under a flange or lip with which the recess is cast. Molten lead is then poured in to hold the dies firmly. When it is desired to remove them, quicksilver is poured into the battery, dissolving the lead and loosening the dies. By retorting the quicksilver both metals are recovered.

The discharge is at both sides and ends. Screens of brass wire-cloth are used, having 40 meshes to the lineal inch, or 1600 holes to the square inch. The stamps crush from a half ton to 1 ton a head each day of twenty-four hours. The batteries are enclosed by housings or closely-fitted boxes, which serve as receivers for the crushed material. The casings are provided with doors, by means of which the workmen can enter and remove the crushed ore by shovelling it into barrows.

Roasting.—The fine ore after crushing is roasted with salt in reverberatory furnaces. These are built of common red brick. Figs. 6911, 6912, show the method of their construction. Fig. 6911 is

6911.





6912.

a horizontal section through the line A B, Fig. 6912. H is the hearth; D the stirring door; *d* the discharge door; G the grate; C the bridge; F the flues; *p* the ash-pit; J the hopper. The charge consists of 1000 lbs. of ore, which is mixed with 6 per cent. of salt, the latter being added to the charge in the hopper, by which the furnace is supplied. The charge is heated very gently at first, the temperature being gradually raised, until at the end it is subjected to a high heat. Usually six hours are required for the roasting. The charge is constantly stirred, and once or twice during the operation it is turned; that is, the portion of the charge remote from the bridge is caused to exchange place with that which is near.

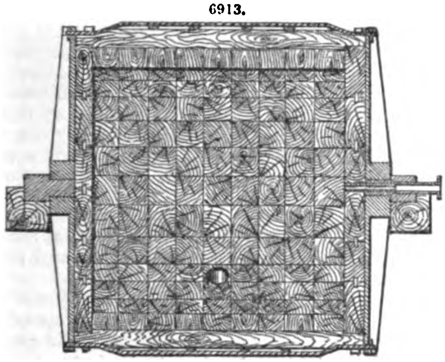
The operation effected by thus roasting with salt consists, very briefly expressed, first, in the oxidation of the metallic compounds, converting the sulphurets, in which form the silver chiefly exists in the ore, to sulphates; and the subsequent decomposition of these combinations by the salt, with the formation of the chlorides of the metals. Sometimes an addition of limestone is made to the charge, for the purpose of decomposing the chlorides of copper, zinc, and so on, thus preventing, to some extent, their subsequent amalgamation in the barrel, and obtaining bullion of a purer quality.

Each furnace roasting four charges of 1000 lbs. each, or 2 tons, in twenty-four hours, consumes one cord of wood. Two stirrers are employed on each twelve-hour shift, making four men in twenty-four hours. One man is required to receive and attend to the ore on the cooling floor, after its discharge. The same man can attend to more than one furnace.

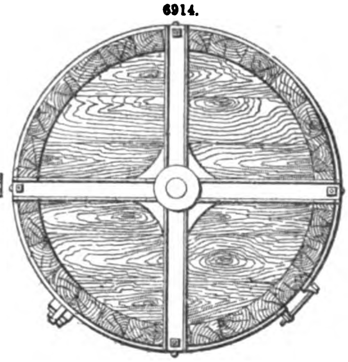
The roasted ore is passed again through a screen, having 1600 holes to the square inch, in order to remove from it any lumps that may have formed by caking in the furnace, or coarse particles that may have escaped the battery-screen. It is then elevated to a large hopper, placed above the amalgamating barrels, to which latter it is thence supplied by means of smaller hoppers, one of which is suspended over each barrel.

The barrels are 4 or 5 ft. in length and diameter. They are usually made of soft pine. Figs. 6913, 6914, are a vertical section and end view of an amalgamating barrel, formerly used at the Gould and Curry Mill. The ends of the barrel are made of plank, fitted together and joined

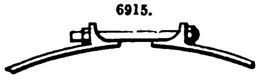
6913.



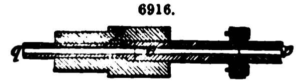
6914.



6915.



6916.



with a tongue of hard wood. The staves of the barrels are sometimes made of 6-in. stuff, without lining; sometimes, as in the figure, the staves are 2 or 3 in. thick, with an interior lining of blocks, 4 or 5 in. square and 3 or 4 in. thick, and so placed in the barrel that the wear is on the end of the grain. This lining can be removed when worn out. The staves of the barrels are bound with iron hoops, the ends of which are drawn together as in Fig. 6915. The ends of the barrel are strengthened by a four-armed flange of cast iron. The barrels are caused to revolve by cog-gearing, the teeth being put on in segments around the end of the barrel; or by belting, or, as at Austin, by friction-gear. The barrel, of which Fig. 6913 is a section, shows a contrivance for admitting steam to the pulp through the trunnion. This arrangement, not very common, consists of a steam-pipe *p*, Fig. 6916, which enters the trunnion and fits smoothly against the end of another pipe *q*, that passes through the end of the barrel and admits the steam to the interior. The interior pipe *q* revolves with the trunnion, while the exterior pipe *p* is fixed and remains without motion. The trunnion T is keyed to the flange already referred to.

The barrels are charged with about 2000 lbs. of ore, mixed with water enough to make a moderately thick paste. Before adding quicksilver, the charge is revolved for two or three hours in the barrel with several hundred pounds of scrap iron. The object of this is to effect a partial reduction of the chlorides present, which would otherwise be performed at the expense of the quicksilver. The chloride of silver is partly reduced by the metallic iron, and is subsequently amalgamated by the quicksilver. The same is true of the lead and copper. Quicksilver is added according to the richness of the ore, usually varying from 250 lbs. to 500 lbs. or more. The barrel is run two hours, at twelve or fifteen revolutions a minute, and then examined, that the consistency of the paste may be ascertained. If the latter is too thin the quicksilver settles on the bottom. This condition is remedied by the addition of more roasted ore; while if too thick for the most favourable distribution of the quicksilver, more water is added. The barrel is then allowed to revolve again for fourteen hours, making fifteen revolutions a minute. The whole time occupied from the charging to the discharging of the barrel is eighteen or twenty hours. When the amalgamation is complete, the paste is thinned by the addition of water, and the quicksilver and amalgam are thus allowed to collect on the bottom of the barrel.

Below the barrels is a large hopper or funnel-shaped contrivance, sloping down from the four sides to a common centre. When a barrel is to be discharged, a small plug in the side is loosened while turned upward; and when the barrel is revolved, so that the plug is downward, it is drawn out by hand. The quicksilver and amalgam are discharged into the hopper, and are allowed to run from the barrel until the pulp begins to follow, when the plug is replaced. When all the barrels ready for that purpose are discharged, the amalgam in the hopper is carefully collected and washed, and afterward cleaned in a common pan like those in use in other mills for similar purposes. The straining of the quicksilver and retorting of the amalgam is performed in manner similar to that already described.

After the hopper below the barrels has been cleaned of all the quicksilver discharged into it, the residue is permitted to flow from the barrels and to run down into a large agitator, 8 or 10 ft. deep, and 12 or 15 ft. in diameter, in which stirring-arms are revolving. By this means the unseparated quicksilver and amalgam are allowed to settle, and the concentrations of this vessel are worked over in pans, while the mass of tailings, passing from the settler, are subjected to further methods of concentration and subsequent treatment.

The different processes by which silver is obtained by the wet way from the various ores and metallurgical products containing that metal, have, in many cases, supplanted the older processes of liquation and amalgamation, and may be often advantageously adopted for the treatment of

argentiferous compounds; particularly when the amount of lead present is small, and the proportion of copper large.

Augustin's process was first introduced in 1849, but after a short time it was superseded by the simpler process of Ziervogel.

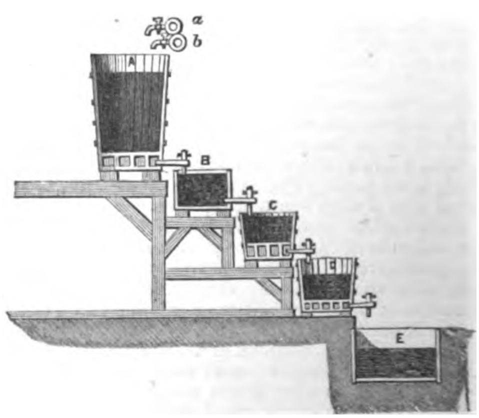
Ziervogel's Process.—The efficiency of this method depends on the circumstance, that when a finely-powdered matt, consisting of the sulphides of copper and iron containing a certain proportion of silver, is, with proper precautions, roasted in a reverberatory furnace, the iron and copper first pass into the state of sulphates, which are afterwards transformed into oxides. The sulphide of silver subsequently undergoes a similar transformation, and, if the roasting were continued, would ultimately be reduced to the metallic state. If, however, the operation is arrested at the proper stage, the copper and iron will have become transformed into oxides, whilst nearly the whole of the silver exists as a soluble sulphate readily removed by water; which thus affords a means of separating that metal from the other constituents of the charge, which are, for the most part, insoluble in that menstruum. From the argentiferous liquors thus obtained, the silver is afterwards precipitated.

The matt, after being ground between a pair of millstones, 4 ft. in diameter, made of the granite, is bolted through a circular sieve, of from 1400 to 1500 apertures to the square inch, and then carefully roasted in a reverberatory furnace, specially adapted to the purpose.

The success of this process depends on the degree of facility with which the operation of roasting may be controlled, so as to be enabled to seize the exact period at which the several metallic compounds are in the precise condition required. The sulphate of copper should be, as far as possible, converted into an oxide, whilst the whole of the silver ought to exist in the form of a soluble sulphate. Should the roasting be arrested before this point has been attained, a large amount of copper will be found to remain in a soluble state; whilst a portion of the silver still exists in the form of an insoluble sulphide. If, on the contrary, the roasting is carried too far, the sulphate of silver will have become reduced, leaving that metal in the metallic state; which, being totally insoluble in the hot water employed for lixiviation, will remain with the copper, and become commercially lost. Long practice and much observation are required on the part of the workmen employed in this process.

The roasted argentiferous matt is taken from the furnace to the lixiviation department, which consists of a large room, in which a number of vessels are arranged, Fig. 6917, and so placed that the liquors flowing from one are immediately received in the next which follows in the series.

6917.



The powder to be operated on is divided into parcels, which are placed in the vessels A, provided with filters and false bottoms; liquor from a previous operation, together with a small quantity of fresh water, both heated to a temperature of 160° Fahr., are run into each of the upper tubs through the pipes *a*, *b*. A little sulphuric acid is also employed. This fluid soon permeating the ore in the tubs A, takes up the sulphate of silver, and any other soluble salts present, which passing through the filter are carried in solution into the tank B, divided into two parts. In this reservoir the liquors enter the first division, and after allowing the matters held in suspension to settle, the solution flows over the partition, and from thence through ten taps into as many tubs C. In the bottom of each of these are placed 10 lbs. of cement copper and 250 lbs. of coarse copper bars, by which the larger proportion of the silver is precipitated in the metallic form. The fourth vessels D, of which there are five, also contain metallic copper, and in them are precipitated any traces of silver which may have escaped precipitation in the tubs C. From these last tubs the spent liquors flow off into the lead-lined cistern E; from which they are subsequently raised by steam pressure into another leaden cistern above the level of the first series of tubs A, heated to a temperature of 160° Fahr., and passed over a fresh charge of roasted matt, introduced into the series of dissolving vessels A.

About two and a half hours are required to dissolve out the sulphate of silver contained in each charge; and at the end of that time the residual contents of the dissolving tubs are transported to an adjoining room, where an assay sample is taken. Should the results of this assay show that the amount of silver remaining is less than 0·00036 of the weight of the material operated on, the residues are placed aside, for the purpose of being fused for blistered copper; but if, on the other hand, they contain more than this proportion of silver, they are re-roasted.

The finely-sifted matt, after being withdrawn from the furnace, is allowed to remain about eight hours before being introduced into the lixiviating tubs, and thus becomes cooled down to about 160° Fahr. before charging. When placed in the tubs, hot water is admitted from *a*, until it begins to escape from the taps at the bottom. The water is then turned off, and hot liquors from a previous operation are introduced from the leaden cistern by the pipe *b*, until the liquid flowing from the cocks at the bottoms of the tubs no longer affords a precipitate of chloride of silver on the addition of a weak solution of common salt. The final liquors collected in the vessel E, when they have become too highly charged with sulphate of copper, are brought in contact

with scrap iron, and thus afford a supply of cement copper, which may be subsequently employed in the tubs C and D.

The process of Ziervogel is, however, adapted to the requirements of comparatively few localities, since the presence of certain impurities, and particularly of any considerable amount of either arsenic or antimony, gives rise to the formation of insoluble salts, which materially interfere with the extraction of silver.

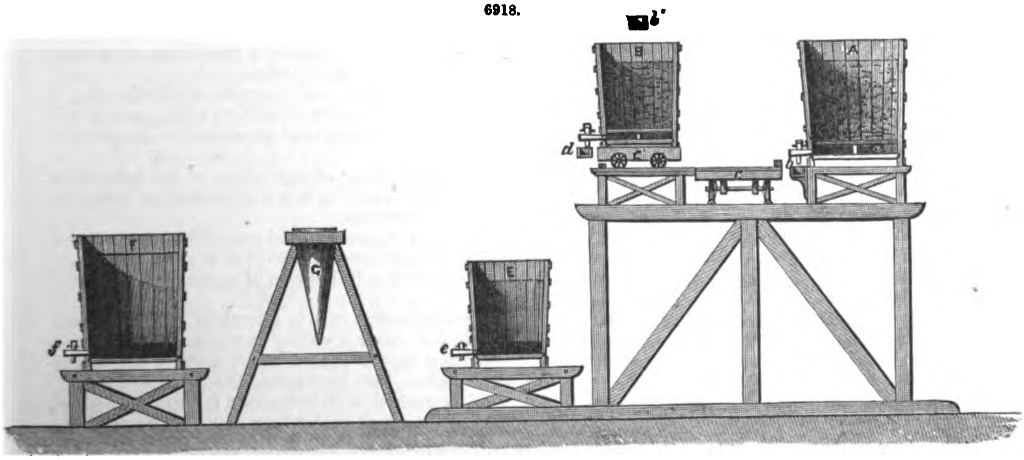
Von Patera's Process.—This method of extracting silver from its ores consists in roasting them with an addition of common salt until the whole of the silver has been transformed into chloride; in dissolving out the chloride of silver by means of a cold dilute solution of hyposulphite of soda; in precipitating the silver in the form of sulphide by the addition of polysulphide of sodium; and in reducing the precipitated sulphide of silver to the metallic state by exposing it in a muffle, at a high temperature, to the ordinary influences of atmospheric air.

The prepared ores are subjected to a process of roasting in a furnace of peculiar construction, and a small boiler, set in brickwork near the furnace, supplies low-pressure steam, which can, when required, be introduced into the tubular bridge, and allowed to escape in numerous jets over the surface of the roasting ore.

The mineral to be operated on is introduced into this furnace, and the heat slowly and cautiously raised. As soon as the charge has arrived at a red heat the tap is turned, and as much steam blown into the hearth as can be safely introduced without so far reducing the temperature as to materially check the activity of the various chemical decompositions which it is desired to effect. At the expiration of four hours from the time of charging, the operation is usually completed; and the ore, after being withdrawn and allowed to cool, is taken to a mill, in which it is ground to a fine powder, with the addition of from 6 to 12 per cent. of common salt, and 2 to 3 per cent. of sulphate of iron. A charge of this mixture, weighing 300 lbs., is now introduced into a similar furnace. This is raised to a red heat, and the steam admitted as before, care being taken to keep the contents of the apparatus constantly stirred. The temperature is now gradually increased, and at the end of from ten to sixteen hours, according to the nature and richness of the ore, the operation is complete.

The apparatus employed for the purpose of solution and precipitation will be understood by reference to Fig. 6918, which represents a vertical section of the whole arrangement.

6918.



In addition to chloride of silver, which is insoluble in water, the ores contain a certain amount of copper, zinc, nickel, cobalt, iron, which, being present in the form of sulphates and chlorides, are readily dissolved in that menstruum. Into each of the tubs A, first series, the roasted ore is introduced, and boiling water is allowed to percolate through the several charges during a period of six hours. By this means all the soluble salts enter into solution, and passing through the filter *a*, are conveyed by the trough *b* into suitable tanks, in which they are precipitated by lime water, and, if found to contain a sufficient amount of silver, are subsequently treated by fusion with lead ores in a blast furnace.

The liquors falling into *b* are from time to time tested by sulphide of ammonium, and as soon as no further precipitate is obtained on adding to a sample a few drops of this reagent, the operation is considered to be finished, and cold water is passed through the tubs for the purpose of reducing the temperature of the residues, which must not until quite cold be subjected to the action of the solution of hyposulphite of soda.

The pulverized ore remaining in the several vessels A, which has been thus freed from all the different salts soluble in hot water, is now transferred to the tubs B, which, like the first, are furnished with filters and false bottoms. These are placed on a level with the tub A, between which and the vessels B is a small railway on which is the car *c*. The tubs B stand on a low truck *c'*, which can be run from the position shown, on to the wagon *c*, and afterwards made to traverse, either backwards or forwards, parallel with and in close proximity to the line of tubs A. The vessel *b*, after receiving a charge of 200 lbs. of the residual ore from one of the tubs A, is taken back to its place and there treated with a cold aqueous solution of hyposulphite of soda

brought from a tank by means of the trough b', and allowed to percolate slowly through the mass. In this way the chloride of silver is taken up in the form of a double salt and passes through the filter in the bottom of the tub into the trough d, by which it is conveyed to the precipitating tubs E, F.

The time necessary for the completion of the operation is more or less influenced both by the richness of the ores and their state of mechanical division, the richest samples containing 15 per cent. of silver, requiring as much as forty-eight hours before becoming sufficiently impoverished; whilst the poorer ones, affording about 1 per cent. of silver, generally require but twelve hours for their treatment. In the case of ores not containing above 7 per cent. of silver, one chlorination and lixiviation is found sufficient, but when richer ores are operated on it becomes necessary to have recourse to two distinct processes of lixiviation, together with an intermediate roasting with salt and sulphate of iron. The lixiviation is known to be complete when the liquors dropping from the tubs no longer afford any traces of a precipitate on the addition of a few drops of sulphide of ammonium, and the residues are then removed, and, after being dried, fused in a blast furnace for copper.

The liquor flowing through the filters in the tubs B is conducted by the trough d into the vessels E, F, of which there are ten, six holding 40 gallons each, and four of the capacity of 80 gallons. The precipitant here employed is a polysulphide of sodium, produced by fusing common soda ash with sulphur, and subsequently boiling the product, dissolved in water, with sulphur in a finely-divided state. The solution thus obtained is taken in large stone jars to the precipitating tubs, and poured into the argentiferous liquors so long as a precipitate is produced by the introduction of an additional quantity. The contents of the tubs, after being well stirred, are allowed to settle, and a sample of the clear liquor having been taken in a test-tube, a little of the solution of sulphide of sodium is added.

If a dark-coloured precipitate is formed, it shows that a portion of the silver still remains in solution, and a further supply of the alkaline sulphide is required in the precipitating vessels. If, on the contrary, the addition of polysulphide of sodium has not the effect of producing a dark precipitate, it becomes probable that too large an amount of the sulphide may have been added to the argentiferous liquor. In order to ascertain this fact, some fresh liquor, holding the double salt of silver in solution, is added to a sample taken from the tub under examination. Should a precipitate of sulphide of silver appear, fresh argentiferous liquor must be carefully added to the tub until no further reaction is observed. When this point has been attained, all doubt as to whether the whole of the silver has been precipitated on the one hand, and that no excess of the precipitant has been employed on the other, is removed by the addition to one sample of a few drops of a weak solution of common salt, and to another, of a small quantity of acetate of lead.

If no precipitate of chloride of silver is produced by the addition of chloride of sodium, it is a proof of that metal having been completely removed; and should no discolouration take place on the addition, to the other sample, of a solution of acetate of lead, it shows that no excess of the precipitant has been added.

Six hours are now allowed for the flocculent precipitate to settle at the bottom of the tubs, after which the clear liquor is siphoned off into a reservoir beneath the floor, and the black slimy sulphide drawn off by the taps e, f, to be placed in a filter-bag of close canvas.

The spent liquors from which the sulphide of silver has been precipitated are afterwards pumped from the tank beneath the floor of the establishment to another above the level of the row of tubs A, from which they are drawn off, as they may be required, for the lixiviation of a subsequent charge of roasted ore.

The pasty sulphide of silver as drawn from the precipitating tubs is placed in conical canvas bags G, supported on wooden frames, and allowed to drain. After standing in the filter until it has ceased to drip, the pasty mass, together with the enclosing bag, is placed under a screw press, and the remaining moisture expressed as completely as possible. The precipitate is now removed from the bag, dried, and, after being replaced in the filter, is washed with hot water for the purpose of removing the adhering soluble salts, of which sulphate of soda is the chief ingredient. The sulphide of silver, thus purified, is again dried, and afterwards heated to redness in a muffle, through which a current of air is allowed to circulate. In this way the sulphur is almost entirely burnt off, and at the expiration of about two hours the entire mass has assumed the metallic condition.

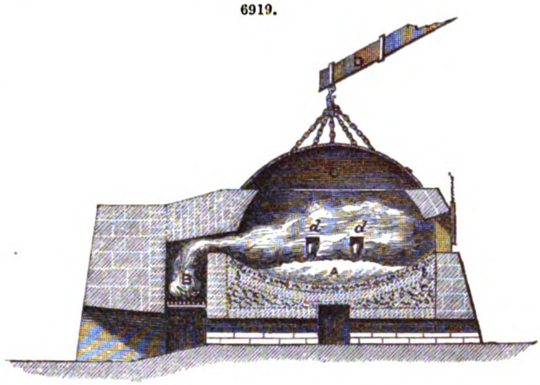
This metallic residue is now fused, in charges of about 300 lbs., in large plumbago crucibles, and any traces of sulphur which it may still retain removed by the addition of metallic iron, with which it forms a ferruginous sulphide readily skimmed from the surface of the metal. A small quantity of a mixture composed of wood-ashes and bone-ash is now thrown on the surface of the metallic bath, and this, on being carefully scraped off, leaves the fused silver in a condition suitable for casting into ingots. Bars produced by this process usually contain from 980 to 985 thousandths of silver.

Smelting.—Cupellation.—The amount of silver extracted from ore by smelting is small compared with that produced by amalgamation; but smelting processes are economically employed when advantage can be taken of the affinity which lead possesses for such ores, when in a fused state. Lead in this condition renders a similar service to that performed by mercury at lower temperatures. The furnace commonly employed on the continent of Europe, where the lead to be operated on is often subjected to cupellation without any preliminary concentration of the silver, is represented, Figs. 6919, 6920, of which the first is a vertical section, and the second a section at the level of the tuyeres.

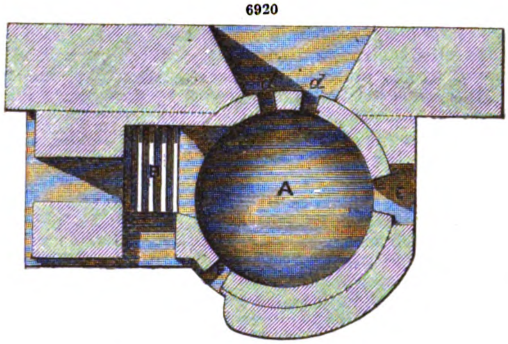
This apparatus is a reverberatory furnace, consisting of a circular hearth A from 9 to 10 ft. in diameter, sloping from all sides towards the centre, built of bricks b, set on edge on a layer of broken slags c. On this is laid a bed of marl a, which is firmly beaten in, when in a damp state, and renewed after each operation. When good marl for this purpose cannot be obtained, a mixture of clay and lime, or clay and wood-ashes, is employed. This bed of marl constitutes the cupel,

which is heated by means of fagots of brushwood burnt in the fire-place B. The roof of this furnace consists of a sheet-iron dome C, which may be suspended by chains from the crane D, and which is internally plastered with clay.

6919.



6920



The cupelling furnace has five openings; one through which the flame from the grate enters the hearth; two, *d*, through which the nozzles pass supplying the blasts to the surface of the metallic bath, for the purpose of oxidizing the lead, and which also assist in carrying the resulting litharge towards the annular space before referred to; the aperture E is employed for the introduction of the discs of lead to be cupelled; and F is that through which the fused litharge makes its escape from the furnace. At the commencement of the operation this last opening is closed by the edge of the layer of marl; but as the cupellation proceeds, it is from time to time cut down, so as to keep the channel constantly at the level of the metallic bath. The litharge thus flowing from the apparatus accumulates on the floor of the smelting house, where it solidifies, and from whence it is removed.

Before commencing a cupellation, it is necessary to prepare the cupel; and for this purpose, after lifting the iron dome, the old cupel, which has become thoroughly impregnated with litharge, is broken up and removed, in order that it may be passed through the blast furnace. The brick bottom of the apparatus is now moistened with water, and successive layers of finely-ground marl are well beaten in whilst in a somewhat damp state. The iron covering is replaced when the cupel has become sufficiently dry, and all the joints are well secured by luting them with clay.

The furnace is now charged with about 8 tons of lead, which, to prevent injury to the bottom, is laid on a bed of straw; the fire is lighted, and the metal rapidly begins to melt. As soon as the fusion of the discs is completed the bellows are slowly set in motion, and the surface of the bath becomes covered with a dark-coloured powder, consisting of oxide of lead, associated with various impurities. These pulverulent matters do not enter into fusion; but the refiner now and then throws a shovelful of coal-dust on the surface of the bath, and by the aid of a billet of wood, fixed crosswise on the end of an iron bar, draws the impure oxides towards the hole through which the litharge escapes, and finally on to the floor of the works. After the expiration of a short time fused litharge begins to make its appearance; but that at first formed, being impure, from the presence of other oxides, is usually laid aside, and not mixed with the purer descriptions which soon follow; these are generally sold for glass-making and other purposes, in preference to being again reduced to the metallic state. The litharge produced during the last period of the cupellation invariably contains a considerable amount of silver, and, after being reduced to the metallic state, forms a portion of the charge worked in a subsequent operation.

The blast is now slightly increased, and the oxidation proceeds rapidly; small flaps, or valves, being frequently fitted to the ends of the nozzles, for the purpose of checking its strength, and distributing it more evenly over the surface of the fused metal. The operation is continued in this way until almost the whole of the lead has been converted into oxide; and the silver, retaining only traces of that metal, remains in the cupel, in the form of a metallic cake.

At the moment the oxidation of lead entirely ceases, a phenomenon known as the brightening takes place, and the operation is then known to be terminated.

As soon as the operation is thus perceived to have terminated, the refiner throws water into the hearth, and removes the solidified cake of silver, which usually still retains a sufficient amount of lead to render its further purification necessary.

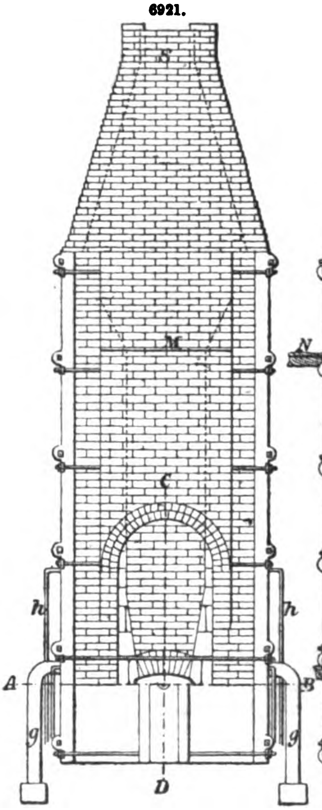
The purification of the silver obtained by the process just described is frequently effected in a small reverberatory furnace, of which the bottom is composed of bone-ash, tightly rammed, whilst in a damp state, into an iron ring, and afterwards so hollowed out as to contain the bath of fused metal. The cupel, which must be thoroughly dry, and ought therefore to be prepared some time beforehand, is, whilst the furnace is still cold, so supported on bricks against abutments prepared for that purpose, as to form the bottom of the apparatus. It is charged with about 1 cwt. of the impure silver to be operated on, and the firing is continued until a bright red heat has been

attained; the silver, which has by this time become fused, being exposed to the oxidizing influences of the flame. In this way the lead contained in the alloy becomes oxidized, and the resulting litharge is absorbed by the cupel, of which the temperature is sustained until the oxidation of all but the last traces of lead has been produced. When this point has been attained, the surface of the fused metal becomes exceedingly brilliant, and reflects, as in a mirror, all the irregularities of the interior of the crown.

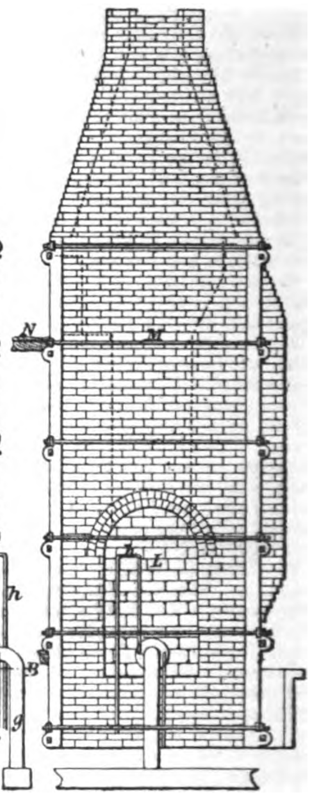
The bottom of the cupel is now pierced by a pointed iron bar, and the silver is run out into moulds, previously heated on a ledge of the furnace. In order to prevent the spirting, or vegetation, of the bars, they are covered whilst cooling by a piece of dry wood, kept down by a weight; and in case of any irregularities making their appearance on the surface of the ingots, they are subsequently removed by hammering. This operation altogether occupies from four to five hours, and the resulting bars usually contain from 997 to 998 thousandths of silver. The actual loss of silver is almost inappreciable; but the diminution in weight experienced, on the crude metal from the cupelling furnace, is from 2½ to 5 per cent.

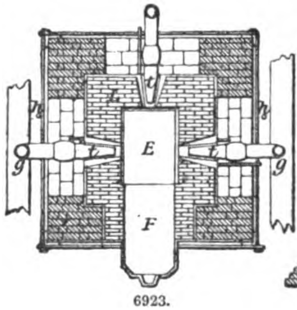
In the English system of treating argentiferous lead, the lead obtained by the different processes before described, in addition to silver, contains various impurities, such as tin, copper, and antimony, which, when the metal is subjected to direct cupellation, are removed by skimming; but when the previous concentration of the silver by crystallization is resorted to, they materially interfere with the operation, and require to be removed by the process of calcination, which consists in keeping the fused lead exposed at a cherry-red heat to the oxidizing influences of the gases passing through a reverberatory furnace, in which the calcination is effected. By this treatment the antimony, copper, and other impurities become oxidized, and, rising to the surface, are skimmed off, and removed by means of an iron rake. The length of time necessary for the purification of hard lead obviously depends on the nature and amount of the impurities with which it is associated; and consequently some varieties will be sufficiently softened at the expiration of twelve hours, whilst in other instances it becomes necessary to continue the operation during several days. The time necessary for sufficiently softening the argentiferous lead obtained from the Castilian furnace, when working ordinary ores, is about thirty-six hours.

6921.

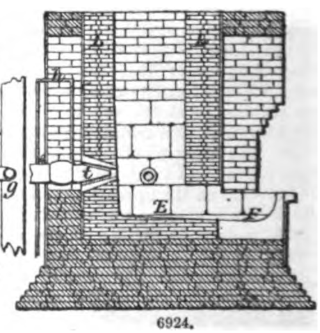


6922.





6923.



6924.

The charge of the reverberatory furnace, which is about 11 tons, is first fused in a large iron pot, set in brickwork at the side, and is subsequently ladled into it through a sheet-iron gutter prepared for that purpose. The amount of coals required for the calcination of a ton of ordinary hard lead is generally somewhat less than 3 cwt. The softened lead is cast into pigs, and is in that form taken to the crystallizing pots.

Smelting in Nevada.—The ore from the Montezuma ledge, Nevada, is of peculiar character, consisting chiefly of the oxides of lead and antimony carrying a small percentage of silver, averaging, by assay, about $80 a ton. It is sometimes hard, massive, and compact in character, while the larger proportion is friable,

showing a fibrous structure. The method of treatment of this ore presents some novelties. It consists of smelting the ore in a shaft furnace, by which means crude metal is obtained, amounting to 40 or 50 per cent. of the charge of ore, and consisting of lead, antimony, and silver. The shaft furnace employed for the smelting of the crude ore is shown by Figs. 6921 to 6924. Figs. 6921, 6922, a front and side elevation; Fig. 6923, a horizontal section through A B; and Fig. 6924, a vertical section through C D of Fig. 6921. The total height of the furnace is about 40 ft. The hearth is built of stone, cut from trachytic rock that occurs a few miles south of the works. The shaft is of common brick, with a lining of fire-brick from the hearth up to the throat.

E is the hearth, or sole; F the sump, or receiver, into which the metal runs on being tapped from the furnace; *t*, tuyeres; *g*, blast-pipes; *h*, pipes to supply water to the tuyeres; L, lining of the furnace; M, throat; N, floor for feeding ore; S, stack.

The capacity of one of these furnaces is from 12 to 13 tons a day of twenty-four hours. The ore being broken into small pieces is spread upon the charging floor and mixed with flux. This sometimes consists of limestone, but generally of slag, or both together. Litharge, the product of the cupelling furnace, is also sometimes used with fresh ore. The ore for the charge, being mixed with about 25 per cent. of flux, is supplied to the furnace with a sufficient quantity of charcoal, that averages about 15 bushels to the ton of ore. About 100 lbs. of the mixed charge and coal is fed to the furnace at once, the supply being continuously kept up as the operation of smelting proceeds. The blast is supplied by a fan-blower, which is driven by the steam-engine.

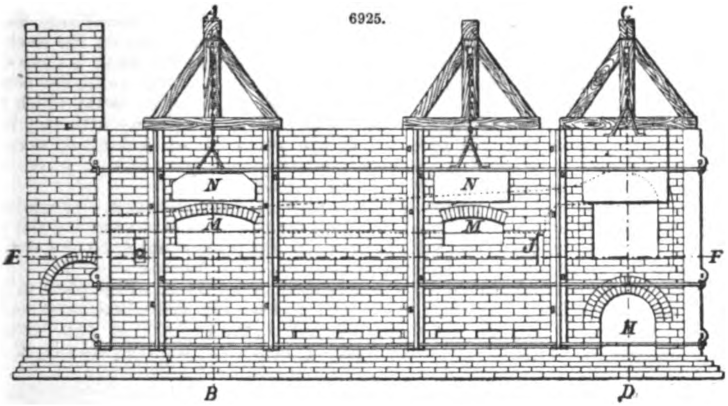
When the furnace is in regular operation the slag is discharged continuously, while the metal is tapped off, at intervals of an hour or two, into an iron receiver, whence it is dipped out and cast in pigs or ingots of convenient size for further handling.

The yield of metal is from 45 to 50 per cent. of the ore smelted; one furnace smelting 12 tons of ore in a day, supplying consequently about 5 tons of crude metal. The ore originally containing $80 a ton in silver, yields metal which contains from $150 to $200 a ton. The slags are constantly examined. Usually they are quite poor, but if found to contain an available percentage of metal, are broken up and returned to the furnace with a fresh charge of ore.

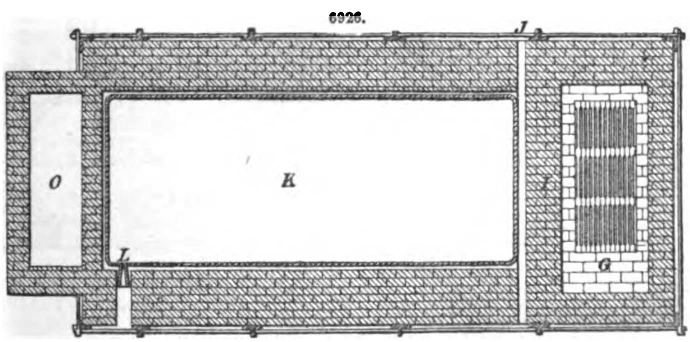
The consumption of charcoal in this smelting process is usually about 15 bushels to the ton, but sometimes exceeds that quantity. It is made from the nut pine.

The refining or calcining furnace for the sublimation of the antimony contained in the crude metal, and the consequent improvement of the lead, consists of a bath or cast-iron pan, about 13 ft. long by 5 ft. 8 in. wide and 8 in. deep, the metal being an inch thick. The pan is set in brickwork, the construction of which is shown by Figs. 6925 to 6928. Fig. 6925 is a side elevation; Fig. 6926 a horizontal section through E F; and Figs. 6927, 6928, transverse sections through A B and C D of Fig. 6925.

6925.



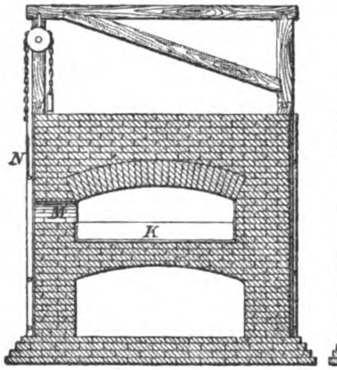
6926.



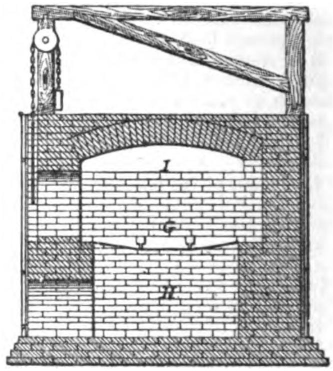
The pan rests on a substantial foundation, and is enclosed by side walls of common bricks, about 10 in. high, over which an arch, Fig. 6928, is turned. A narrow space is left between the

pan and the enclosing masonry to allow for expansion. At one end of the structure is a fire-place and ash-pit; the flame passes over a bridge which separates the fire-place from the pan, and thus

6927.



6928.



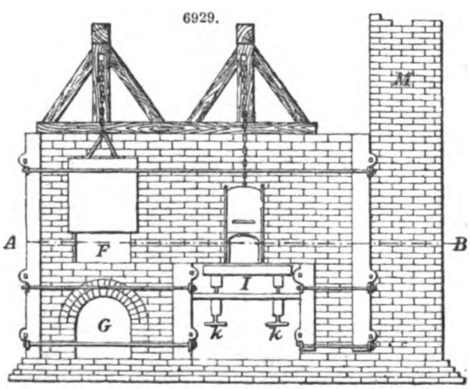
over the surface of the metal contained in the pan toward the stack at the opposite end. There is a horizontal channel passing through the bridge behind the pan, opening at the sides of the furnace and communicating by vertical passages with the interior, by which means air may be admitted to the charge. Doors are provided in the side of the furnace for the purpose of skimming off a crust or scum, consisting of lead and antimony, that collects on the surface while the operation of calcining is in progress. The charge is also introduced through these doors. There is a tap near the end of the pan on one side for the purpose of drawing off the refined metals. At the base of the stack is a chamber for the collection of the oxidized antimony that may condense in the slack and fall to the bottom. The whole structure is firmly bound together by irons and bolts. In the figures, G is the fire-place; H the ash-pit; I the bridge; J the air-channel through the bridge; K the pan; L the spout; M the openings for putting in and working the charge; N the doors; O the chamber at base of stack for the accumulation of the oxidized antimony.

To set this furnace in operation the metal may be first melted and introduced in a fused state to the pan, or, what is more common, the pan is heated to redness and the pigs of crude metal are laid upon the pan-bottom, when melting ensues. The fire may be quite moderate, the only fuel used in this case being sage brush. The antimony is oxidized and passes up the stack, a part to escape, a part condensing in the chimney. The charge of the pan at the outset is some 6 or 8 tons, but as the molten metal diminishes in bulk by the sublimation of the antimony new bars are added to keep up the supply. A scum collects on the surface of the molten metal, which is removed by scrapers from time to time. This consists chiefly of lead and antimony with very little silver. While this refining process was still practised at the works, these skimmings were collected, remelted, and cast in bars to be sold for type-metal, Babbitt-metal, and other purposes. The alloy consisted of 71 per cent. of antimony with 29 per cent. of lead.

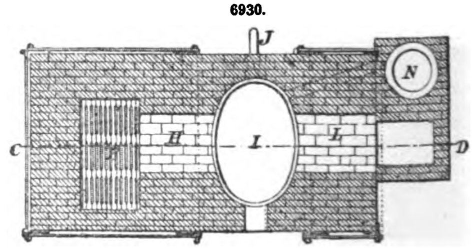
The lead in the pan is gradually enriched by this method of concentration, and assays are taken from time to time, usually at intervals of twelve hours, for the purpose of watching the progress of the operation. When the value of the lead has been brought up to about \$350 or \$400 a ton, it is drawn off in moulds, and then subjected to treatment in the cupel furnace.

The cupelling furnace is of the kind commonly used in England. Figs. 6929 to 6931 show the method of its construction. Fig. 6929 is a side elevation; Fig. 6930, horizontal section on the line A B of Fig. 6929, and Fig. 6931 is a vertical section on the line C D of Fig. 6930. F is the fire-place; G the ash-pit; H the bridge; I the test-ring, or hearth; J the tuyere; K, K, supporting

6929.



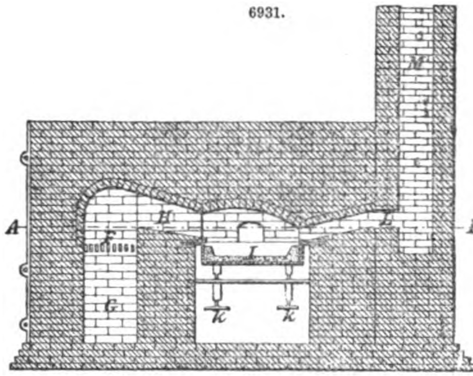
6930.



and adjusting screws for the test-ring; L the flue leading to the stack M; N a melting pot or pan in which the metal may be prepared for the hearth.

The hearth consists of bone-earth, prepared from the bones of cattle. The bones are burned and then pulverized in the stamp-mill, and being moistened with water that contains a little alkali, leached from wood-ashes, the mass is beaten compactly into the test-ring. This is oval in form, being 4 ft. long by 3 ft. wide. It is a rim of iron 7 or 8 in. deep, having bars across the bottom to sustain the hearth of bone-earth. The latter being prepared in the rim it is very carefully dried, and the ring is then introduced into the cupel chamber, supported upon screws, by means of which it may be elevated or lowered, or inclined in one direction or another. When properly adjusted, it is heated, very gently at first, in order to avoid cracking. The heat from the fire-place passes over the bridge into the cupel chamber, and thence by the flues to the stack. When the hearth is well heated the lead is placed upon it, and a blast of air is introduced by means of a fan-blower and tuyere.

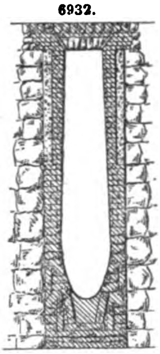
6931.



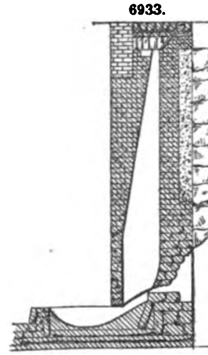
This acting upon the surface of the lead, the metal is oxidized, and the resulting litharge is allowed to run off through gutters made for its passage, in the surface of the hearth, into vessels placed below for its reception. As the lead is gradually oxidized, fresh supplies of metal are introduced, either in the form of pigs or in a molten state, the pan N being provided for the purpose of fusing the metal if desired. By this means the metal on the hearth is constantly enriched, and when the button of accumulated silver has become as large as may be desirable, the addition of lead is discontinued and the oxidation carried on until the lead is nearly all removed, leaving a mass of silver, of a high degree of fineness, upon the hearth. The litharge produced by this operation contains some silver. The richer portion is returned to the shaft furnace and mixed with the charge of fresh ore.

Smelting in Sweden.—At the Sala mines the ore is obtained in the form of argentiferous galena, with which is found a variety of other metallic sulphides, as pyrites, zinc blende, and so on. The ore, after being carefully sorted, washed, and stamped, is partially treated in a blast to a first smelting. It is afterwards operated upon in two blast furnaces, similar to that represented in Figs. 6932, 6933. The hearth is made of brasque, and is prolonged outwards and forwards, thus forming a fore-hearth. The charge is composed of the richest ore from the first crushing, and of the slimes from the washing process, together with the regulus obtained from the first smelting and that derived as a by-product during the second smelting, the regulus having been first calcined in an open kiln. Formerly the ores also were subjected to a previous calcination, but the ores are now smelted in a raw state. It is from these substances—stuff, slime, and regulus—that the argentiferous lead obtained in this process is derived; other ingredients being introduced partly to produce a good fusible slag, and partly to assist in freeing the metals from their combination with sulphur. For the formation of a slag, the proportion of which must bear a proper relation to the production of metal and regulus, there is added some easily fusible slag, containing less lime and more protoxide of iron as bases, such a slag as that obtained from the lead smelting.

6932.



6933.



The chief points are, that it flow easily, and that it contain sufficient protoxide of iron; hence it should be composed of tribasic silicates, because the presence of a greater proportion of silica in the slag increases the loss both of the silver and the lead. To assist in reducing the lead from its sulphuretted condition, metallic iron was formerly employed; but it has been found that the use of it may be dispensed with by introducing a proper admixture of iron pyrites in addition to the regulus from the lead and the raw-smelting; both the pyrites and the regulus having been previously calcined, the amount of protoxide of iron which these contain appears to be sufficient to assist the reduction and to induce the formation of a good slag. These substances are charged in the following proportions;—

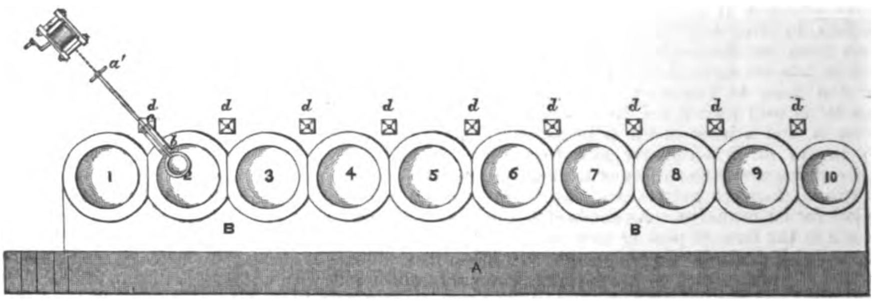
	Parts
Stuff ore, containing on an average from 0·13% to 0·28% of silver, and 14% to 34% of lead	100
Slimes from the washing, containing on an average from 0·2% to 0·25% of silver, and from 23% to 31% of lead	125
Roasted regulus, containing about 0·125% of silver	96
Roasted iron pyrites	18
Slag from previous lead-smelting	750

To which are added the old cupel hearths and litharge derived from the cupel. The product of this smelting consists of ore-furnace lead containing an average of 86 per cent. of silver, regulus, and slags. The lead is cupelled and the silver refined in an ordinary way.

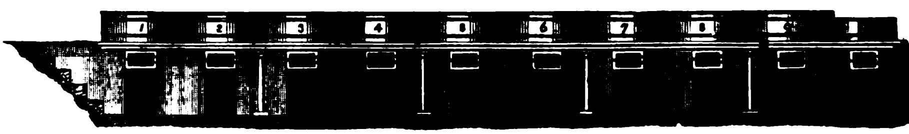
Pattinson's Process.—This process is founded on the circumstance, first noticed in the year 1829, by H. L. Pattinson, of Newcastle-on-Tyne, that when lead containing silver is melted in considerable quantities in suitable vessels, allowed slowly to cool, and at the same time kept constantly stirred, at a temperature near the melting point of lead, metallic crystals begin to form. These sink to the bottom, and, on being removed, are found to contain much less silver than the lead originally operated on. The still fluid portion, from which the crystals have been thus removed, will at the same time be found to be proportionately enriched.

This operation is usually conducted in a set of from 9 to 12 pots, which, if worked by hand, each contain 6 tons of metal; or, if cranes be employed, are 5 ft. 4 in. wide and 2 ft. 6 in. deep, and contain 10 tons of argentiferous lead. Each of these pots, Figs. 6934, 6935, is provided with a separate fire-place, the heat from which is made to pass around it by means of a wheel flue, which can be closed at pleasure by a damper; the products of combustion finally escape into a large arched flue parallel with the line of pots.

6934.



6935.



We will suppose that the lead under treatment contains about 20 oz. of silver a ton, and is introduced into pot 5, Fig. 6934. This metal when fused is carefully skimmed with a perforated ladle, and the fire at once withdrawn. The cooling of the metal is now hastened by sprinkling water on its surface; and whilst the temperature is being thus lowered, it is kept constantly stirred with a chisel-pointed iron bar, called a slice. All those portions which become solidified, and adhere about the side of the pot, are also removed and forced under the surface of the metal, in order that they may again become melted. Under this treatment, crystals soon begin to make their appearance; and as they fall and accumulate at the bottom, they are removed by means of a large perforated ladle, in which, after being well shaken, they are first allowed to drain over the pot whence they have been taken, and afterwards carried over to the next pot, 6, to the left of the workmen. This operation is continued until about two-thirds of the lead originally present in pot 5 has been transferred into the form of crystals to pot 6, at which period the lead remaining in pot 5 will contain about 40 oz. of silver a ton, whilst that transferred to 6 yields only 10 oz. The rich lead in the bottom of 5 is now ladled into the pot 4 next on the right.

In this way a fresh supply of calcined lead is constantly introduced, the resulting crystals passing continually to the left of the feeding pot, whilst the enriched lead, remaining in the bottom, is ladled into the pot on the right. Each pot in succession, when it has become filled with metal of the proper produce for silver, is in its turn crystallized; the poor lead passing to the left, and that which has become enriched to the right in the series. By this means the crystals obtained from the pots to the left of the feeding pot gradually become deprived of their silver, whilst the rich lead passing to the right is continually enriched. The final result therefore is, that at one end of the line of kettles the lead contains but little silver, whilst at the other extremity it becomes exceedingly argentiferous.

The desilverized or market lead obtained by this process should never contain above 12 dwt. of silver a ton, and is frequently much poorer, whilst the rich lead is sometimes so concentrated as to yield 600 oz. a ton. This rich lead is passed to the refining furnace for cupellation.

The ladle employed, when manual labour is made use of, is 16 in. in diameter, 5 in. in depth, and pierced with ½-in. holes. When cranes are employed, the ladles are 20 in. in diameter, 6½ in. in depth, and are pierced with holes ¾ in. diameter; thickness of iron, ½ in.; length of ladle, 9 ft. 4 in. The large baling ladles used for turning back the bottoms are 14 in. in diameter and 8 in. deep, and have a handle 7 ft. long.

Two crystallizers are employed in working each pot, and one fireman every twelve hours is required for each set. By the use of cranes a 10-ton pot can be worked as quickly, and at the same expense for labour, as a 6-ton pot by hand ladles.

Fig. 6934 is a plan, and Fig. 6935 an elevation, of a set of Pattinson's pots, fitted with cast-iron cranes arranged according to the most approved system; 1 to 9 are working pots, and 10 the market pot, out of which the desilverized lead is ladled into moulds; and which, from only receiving the

crystals from 9, and not having a bottom of enriched lead left in it, has only two-thirds the capacity of the other pots.

A long ash-pit A extends the whole length of the set, and is partially covered by the iron platform B, supported on iron pillars. The fire-places *a* are provided with iron doors.

When, during the operation of taking out crystals, the perforated ladle becomes chilled, it is heated to the proper temperature by being dipped into the pot of hot lead into which they are turned over.

In order to work by the aid of this arrangement, the potman sinks the ladle sidewise to the bottom of the kettle, and having turned it over, so as to be full of crystals, he attaches a hook to the cross-handle *a'* of the ladle, Fig. 6934, which is then withdrawn by the other workman turning the winch.

In doing this, the iron shank slides over the roller *b*, at the end of the crane *d*; and as soon as it is withdrawn from the fused metal, the first workman, who guides the handle during the operation, slips it into one of the cheeks *c*, at the back of the crane, where it becomes firmly secured. The ladle, full of crystals, is thus suspended over the pot from which it has been withdrawn, and after being allowed a short time to drain, it receives a few shakes by jerking the iron handle. The crane is now swung round, the shank slipped out of the catch, and the crystals deposited in the next pot on the left. This is continued until the necessary amount of crystals has been withdrawn, when the rich lead remaining in the bottom is taken out, in the same way, by a ladle without perforations, and turned over in the next pot on the right. In some establishments the lead remaining in the bottom of the rich pot 1 is further concentrated by allowing it to cool to the crystallizing point, and then pressing it with the convex side of one of the large perforated ladles. The still liquid alloy is thus made to enter the bowl through the holes with which it is pierced, and is taken out with a smaller unperforated dipper. The lead thus obtained will evidently be richer than the crystals remaining in the kettle.

Assay of Silver.—The assay of argentiferous galena is, in England, usually conducted in a wrought-iron crucible of plate iron, of good quality, turned up in the form of a crucible, and carefully welded at the edges; the bottom is closed by a large iron rivet, securely welded to the sides, and the whole finished by the hammer on a properly-formed mould. To make an assay in a crucible of this description, it is first placed in the assay furnace, and heated to dull redness; and when it has become sufficiently hot, 400 grains of the pulverized ore, intimately mixed with its own weight of soda-ash, about 30 grains of pearlash, and from 8 to 10 grains of charcoal powder, or lamp-black, are introduced by means of a long copper scoop. With certain varieties of ore, the addition of a small quantity of common salt, or fluor spar, is found to be beneficial for the production of a thoroughly liquid slag; fluor spar being particularly advantageous in the case of highly silicious ores. On the top of this is placed a thin layer of dried borax; and the crucible, which, for the introduction of the mixture, has been withdrawn from the fire, is at once replaced in the furnace. At first the contents of the pot boil somewhat violently, and therefore, in order to avoid loss, the crucible should be made of sufficient capacity to prevent any portion of the mixture being projected over its sides. At the expiration of from eight to ten minutes, the ingredients in the crucible will be observed to be in a state of tranquil fusion; and the pot must now be removed from the fire, and its contents briskly stirred by means of a small iron rod, flattened at the end in the form of a spatula. Any matters adhering to its sides are also scraped downward into the bottom of the pot, which is replaced in the furnace, and, after being closed with an earthen cover, is, during three or four minutes, heated to full redness.

The crucible is now seized by a strong pair of bent tongs on that part of its edge which is opposite to the lip; and, after being removed from the fire, its contents are rapidly poured into a cast-iron mould, having internally the form of an ordinary egg-cup. The sides of the pot are now carefully scraped down with the chisel-edged bar before referred to, and any adhering particles of lead and slag are obtained by sharply striking the edge of the crucible against the top of another cast-iron mould, similar to that into which the assay was first poured. When sufficiently cold, the contents of the mould are readily removed by merely turning it over; and the metallic button, after being separated from the adhering slag, is carefully cleaned by means of a hard brush, and weighed, in order to determine the percentage yield of lead. When a metallic shot has been obtained in the second mould, it must be freed from adhering slag, and weighed with the larger button. The alloy thus obtained is cupelled, in order to determine the amount of silver which it contains.

Ores of silver, in which that metal exists in the form either of oxide, sulphide, or chloride, in a gangue principally consisting of silica or of carbonate of lime, are usually fused with a mixture of litharge and carbonate of soda, to which a small quantity of finely-powdered charcoal is added; and by this means a button of alloy is obtained, which is subsequently treated by cupellation.

The proportion of litharge to be employed for this operation must be varied in accordance with the circumstances of the case, as the resulting button of alloy should not be too rich in silver, since, in that case, a portion might be lost in the slags; neither should it, on the other hand, be too poor, as the cupellation would then occupy a long time, and a loss through absorption be the result. In ordinary cases, where the silver principally exists in the form of chloride and sulphide, and the quantity operated on is 400 grains, a button of alloy weighing about 200 grains will be a convenient amount for cupellation. Such a result may generally be obtained by the addition of 300 grains of litharge, 400 grains of carbonate of soda, 150 grains of borax, and from 7 to 8 grains of finely-powdered charcoal. The whole is to be well mixed, and introduced into an earthen crucible, of which it should not occupy more than one-half the capacity.

The crucible is now placed in an assay furnace of the usual form, care being taken to withdraw it from the fire as soon as a thoroughly liquid and perfectly homogeneous slag has been attained. When it has sufficiently cooled, the crucible is broken and the metallic button obtained, which, after being properly cleaned, is passed to the cupel. When a great degree of accuracy is required, it is always best to break the pot; but when numerous assays have to be made on ores of nearly

the same tenure, the assay is sometimes poured into an iron mould, and the crucible is employed for making other fusions. In this, and all similar cases, it is, of course, essential to ascertain, by previous experiment, the proportion of silver contained in the lead obtained by the reduction of the litharge, in order to obtain the necessary data for calculating the requisite deduction to be made from the results afforded by cupellation. When, however, very poor litharge is made use of, the resulting lead contains so small an amount of silver that, for some commercial purposes, its presence may be disregarded; generally speaking, however, the assayer, on the receipt of a fresh supply of that reagent, ascertains, by means of careful assays, the proportion of silver which it contains, and makes the necessary correction on each assay in which it is employed.

Argentiferous minerals containing a considerable amount of copper may be generally assayed by this process, since the amount of that metal which enters into combination with the lead produced is comparatively small, and the resulting button of alloy admits of being readily cupelled by the addition, when necessary, of metallic lead. When the mineral to be assayed contains a large proportion of metallic sulphides, the addition of charcoal, or any other reducing agent, becomes unnecessary, as litharge readily attacks all the simple and complex metallic sulphides, oxidizing their constituents, with the exception of the precious metals, which form an alloy with the lead set free. The slags resulting from this operation contain the excess of litharge added, and the button of alloy produced is subjected to cupellation. The proportion of oxide of lead to be added to ores of this description varies in accordance with their composition, but it should in all cases be present in decided excess, since, should the sulphides not become completely decomposed, the whole of the silver will not be concentrated in the resulting button of alloy. For the successful assay of pure argentiferous iron pyrites, as many as 50 parts of litharge are required, whilst for mispickel, blende, copper, pyrites, grey cobalt, and sulphide of antimony, from fifteen to twenty times their weight may be employed.

It must, however, be remembered that earthy and silicious gangues usually constitute a large proportion of the bulk of the ores operated on, and consequently these excessive amounts of litharge are, in practice, seldom requisite. One of the chief objections to this method of assay is the large amounts of lead that are produced for cupellation, since pure iron pyrites afford 8·50 parts of this metal, whilst sulphide of antimony and grey copper ore yield from 6 to 7 parts.

This inconvenience may be obviated by effecting the partial oxidation of the sulphides, either by roasting or through the aid of nitre, by the skilful use of which a button of almost any required weight may be obtained. If this reagent is employed in excess it determines the oxidation of the various metallic and other oxidizable substances present, not always excepting silver itself. When, however, the mixture at the same time contains an excess of litharge, and nitre has not been added in sufficient quantity to effect the decomposition of the whole of the sulphides present, reaction takes place between the portion of sulphide undecomposed and the oxide of lead added. This gives rise to the formation of a button of metallic lead, which, combining with the silver, affords a button of alloy suitable for cupellation. The amount of nitre required to be employed for this purpose necessarily depends on the nature and richness of the ore operated on, but it must be borne in mind that 2·5 parts of nitrate of potash are sufficient to completely oxidize the constituents of iron pyrites, and that 1·5 and 0·70 parts respectively are, in the case of sulphide of antimony and galena, sufficient for this purpose.

When the ores contain a large proportion of sulphides, it is generally found most desirable to conduct the assay on the mineral after calcination. The roasting of the pulverized ore is best effected in a shallow scorifier, or earthen dish, into which a weighed quantity of the mineral to be operated on, generally 400 grains, is introduced, and then carefully roasted in the muffle of a cupelling furnace. For this purpose the scorifier and its contents should be first placed in the mouth of the muffle, and kept constantly stirred with a thin bent iron rod; care being taken to commence the operation at a low temperature, since, from their great fusibility, such ores would be otherwise liable to agglutinate. As the calcination progresses, the scorifier may be gradually pushed farther into the muffle, and thus subjected to successively increasing temperatures; as soon as sulphurous vapours are no longer evolved at a full red heat, the scorifier and its contents are withdrawn and allowed to cool. The ore, when sufficiently cold, is carefully removed from the earthen dish, and mixed, on a sheet of glazed paper, with the fluxes requisite for effecting its fusion, and the reduction of the quantity of lead necessary for cupellation. When the amount of mineral operated on is 400 grains, there should be added soda-ash 400 grains, borax 200 grains, litharge 400 grains, and charcoal 10 to 12 grains. The whole is now introduced into an earthen crucible, fused with the usual precautions, and the resulting button of lead passed to the cupel.

This is a simple and convenient method of assaying ores containing the precious metals, when large quantities of metallic sulphides are present. The process consists in subjecting the finely-pulverized minerals, mixed with granulated lead and placed in a saucer-shaped earthen vessel or scorifier, to the action of a bright red heat in an ordinary assay muffle. A portion of the lead is thus converted into litharge, which, as fast as it is produced, combines with the various silicious and earthy constituents of the veinstone, forming slags, in which the other metallic oxides produced are taken up, whilst the silver and gold form an alloy with the lead remaining at the close of the operation. The scorifiers employed for this purpose should be made of well-baked close-grained fire-clay. It is necessary that they should be compact in their structure in order to resist the corrosive action of the litharge, and that they should be capable of withstanding sudden changes of temperature without breaking.

A number of these scorifiers, corresponding to that of the assays to be made, are selected, and into each are introduced 100 grains of powdered raw ore, intimately mixed with from five to eight times its weight of granulated lead, and a small quantity of dried borax. In all cases, however, the lead should be added in excess, as the resulting slags are thereby rendered more liquid. The granulated lead used for this purpose should, if possible, be almost entirely free from silver, but this is difficult to obtain, and when it cannot be procured it becomes necessary to estimate before-

hand the amount of silver contained in the lead employed, and to make a corresponding deduction from the weight of the button afforded by cupellation.

The scorifiers, after being duly charged with the ore, lead, and borax, are taken to the furnace and introduced into the muffle, which has been previously brought to a full red heat. Their introduction at first considerably reduces the temperature of the furnace, and some pieces of charcoal should be placed in the opening of the muffle for the purpose of again raising the heat to the proper point. The muffle door is now closed, and in the course of a few minutes the lead enters into fusion, whilst white vapours are observed to rise from the assay, and the formation of litharge rapidly takes place. In proportion as the borax fuses, and the quantity of litharge increases, the contents of the scorifier soften; and as the temperature becomes more elevated, they enter into fusion, whilst the lead accumulates in the centre in the form of a large metallic globule.

When the assays have reached a bright red heat, which is usually the case in from ten to fifteen minutes from the commencement of the operation, the stopper of the muffle is removed; and the current of air which now enters causes the oxidation of the lead to proceed more rapidly. In proportion as the litharge accumulates, the slag formed by its combination with the earthy, silicious, and other matters contained in the ores, increases in quantity, and gradually extends itself over the whole surface of the lead. The door of the muffle is allowed to remain open about fifteen minutes, at the expiration of which time it is again closed, and the temperature is raised for about five minutes to full redness, for the double purpose of rendering the scoriæ as liquid as possible previously to pouring, and also to facilitate at the same time the reunion of any disseminated globules of metallic lead.

The scorifiers are now withdrawn by means of proper tongs, and their contents rapidly poured into moulds. When sufficiently cold, the buttons of lead are detached from the adhering slags by being hammered on a small anvil, and are then passed to the cupel. When this operation has been successfully conducted, the resulting buttons of alloy contain, practically, the whole of the precious metals present in the ore. It is, however, essential that the slags should be perfectly and uniformly liquid at the time of being poured into the moulds, for should they either be pasty or contain imperfectly-fused lumps, a portion of the mineral will remain unacted on, and small metallic buttons may either be enclosed in the unfused part, or remain attached to the scorifier.

When, in spite of the temperature of the muffle and the other conditions of the process having been carefully attended to, the slags do not become sufficiently liquid, it is necessary to introduce an additional quantity of borax, and in some cases a little nitre may be added with advantage. Sometimes, although rarely, it is found necessary to stir the slags with an iron rod, for the purpose of dividing any lumps that may have been formed, and to incorporate them with the more liquid scoriæ.

The cupellation of the buttons of argentiferous lead is conducted as described when treating of the assay of auriferous compounds, but as silver is at high temperatures more volatile than gold, the heat requires to be more carefully regulated than is necessary in the case of gold ores. In making all cupellations, it is necessary to bear in mind that a cupel is only capable of absorbing about its own weight of litharge, and consequently a test should always be employed a little heavier than the button of alloy to be subjected to the operation.

The results obtained are also to a certain extent influenced by the temperature at which the cupellation has been conducted, and consequently all assays are liable to a small amount of error. If the muffle is too strongly heated, the silver becomes perfectly refined, but experiences a small amount of loss through sublimation and the absorption of the cupel; whilst, on the contrary, when the temperature has not been sufficiently elevated, the button is liable to retain a small portion of lead. These two causes of error, existing at the same time in all cupellations, are often found in practice to nearly neutralize each other; although, in order to obtain uniform results from the same alloy, it is necessary to employ various minute precautions, both with regard to the temperature of the muffle and the condition of the cupels employed.

When, however, the amount of lead employed has been sufficient, the cupel is perfectly dry, is made of fine and well-prepared bone-ash, and the cupellation is conducted at a full cherry-red heat, the results obtained will, in almost all cases, be found of a satisfactory character. If the resulting buttons of silver be large, they should not be abruptly withdrawn from the muffle, but be gradually drawn towards its mouth, since their sudden removal might cause them to spirt. In the case of a very large button being obtained, it is sometimes found advantageous to cover it, immediately after brightening, and before its removal from the muffle, by another cupel kept hot for that purpose.

When it has sufficiently cooled, the metallic button is seized laterally between the jaws of a pair of strong pliers and tightly squeezed, for the double purpose of loosening it from the cupel and detaching any adhering litharge. The button is then cleaned by the aid of a stiff brush, and weighed in a delicate assay balance. When, in addition to silver, the mineral under examination contains gold, the button obtained on the cupel is first weighed, and its weight noted; it is then flattened, dissolved in nitric acid, and the gold also weighed; the difference of the two weights thus corresponds to the amount of silver present in the assay.

The weight of mineral employed for making an assay is, to a great extent, regulated by the amount of silver which the ores are supposed to contain. In Cornwall, for assays of argentiferous galena, the quantity operated on is often 1 oz. avoirdupois. In Nevada, 200 grains are commonly made use of, and the contents of the crucible are often poured out into an iron mould. Scorifications are not easily conducted, in the common muffle furnace, on much above 100 grains; but for assays of an ordinary silver ore by fusion, 400 grains are conveniently employed.

For commercial purposes, the silver contained in any given mineral is in England estimated in oz., dwt., and gr., 1 ton of 2240 lbs. avoirdupois being taken as the standard.

The details of the various methods for the reduction of silver ores are to a great extent modified in accordance with the resources of the districts in which they are employed, and consequently even a brief notice of all of them would have occupied more space than was at our disposal for the

purpose. We have therefore confined ourselves to descriptions of the more important and general methods, and of such as can be taken as types of the several systems which they represent. See FURNACE. GOLD. LEAD. ORES, *Machines and Processes employed to Dress.*

Works relating to the subject;—Lamborn (Dr. R. H.), 'The Metallurgy of Silver and Lead,' 12mo, 1861. Phillips (J. Arthur), 'The Mining and Metallurgy of Gold and Silver,' royal 8vo, 1867. Kerl's 'Metallurgy,' by Crookes and Röhrig, vol. i., 8vo, 1868. Percy (Dr. John), 'The Metallurgy of Lead,' 8vo, 1870. "U. S. Geological Exploration of the 40th parallel," vol. iii., 'Mining Industry,' by J. D. Hague and Clarence King, 4to, with atlas, Washington, 1870. Raymond (R. W.), 'Statistics of Mines and Mining,' 8vo, Washington, 1869–72.

SLEEVE. FR., *Manche*; GER., *Helm*; ITAL., *Manica*; SPAN., *Dedal largo.*

In machinery, a *sleeve* is a tubular part, resembling in form or position the sleeve of a coat, to cover, sustain, or steady another part that moves within it. A long bushing or thimble is called a sleeve, as in the nave of a wheel.

SLOTTING MACHINE. FR., *Machine à buriner*; GER., *Stossmaschine*; ITAL., *Pialla verticale*; SPAN., *Máquina para hacer muescas.*

See MACHINE TOOLS.

SPINDLE. FR., *Broche*; GER., *Spindel*; ITAL., *Alberetto*; SPAN., *Huso.*

A spindle is a slender pointed rod or pin upon which anything turns; an axis, or arbor; as, the spindle of a vane, a pinion, or a capstan. The *dead spindle* is the arbor of a machine tool that does not revolve; the spindle of the tail-stock. The *live spindle* is the revolving arbor of a machine tool; the spindle of the head-stock.

SPIRAL-WHEEL. FR., *Roue hélicoïdale*; GER., *Spiralrad*; ITAL., *Ruota elicoide*; SPAN., *Rueda espiral.*

See MECHANICAL MOVEMENTS.

SPUR-WHEEL. FR., *Roue dentée*; GER., *Stirnrad*; ITAL., *Ruota dentata*; SPAN., *Rueda de engranaje.*

See MECHANICAL MOVEMENTS.

SQUEEZER. FR., *Machine à cingler*; GER., *Presse*; ITAL., *Strettoio del ferro*; SPAN., *Apretador.*

See BLOOMING MACHINE. IRON.

STATIONARY ENGINE. FR., *Machine fixe*; GER., *Stationaire Dampfmaschine*; ITAL., *Macchina fissa*; SPAN., *Máquina fija.*

The stationary engine is the most perfect form of the steam-engine we possess. In the locomotive and the portable types, by reason of the conditions which they have to fulfil, it is impossible to apply many of those means by which steam, and consequently fuel, is economized, and the efficiency of the engine increased. In the stationary engine, any and all of the means by which these objects may be attained may be adopted, because the conditions under which it works admit of any modification being effected in the form or the arrangement of the various parts. Hence we find, in this type, economy of steam carried to its highest degree, and the most successful modes of applying it advantageously. It is for this reason that the discussion of certain improvements in the steam-engine has been reserved for the present article, which improvements, though applied to some extent to other types of engine, yet originated in this, and belong more properly to it.

Stationary engines are of two kinds, called respectively low-pressure and high-pressure engines. These terms do not refer to the initial pressure of the steam in the cylinder, but to its final pressure. The terms are, however, inappropriate, since they do not express the distinctive difference between the two varieties of engine. This difference may be briefly expressed as follows;— The high-pressure engine discharges its steam directly into the atmosphere; and consequently the steam on leaving the cylinder must possess an elastic force equal to at least 15 lbs. to the inch. The whole of this force is of course wasted. The low-pressure engine condenses its steam and discharges it as water, and consequently the pressure of the steam on leaving the cylinder may be much less than that of the atmosphere. Thus a large proportion of the steam wasted by the high-pressure engine is utilized. The terms condensing and non-condensing would therefore be far more appropriate than low and high pressure.

The condensing engine is provided with a separate vessel to condense its steam in; this vessel is called the condenser, and is in direct communication with the cylinder. When the piston has completed its stroke, the exhaust-port is placed in communication with the condenser, into which the steam at once rushes. To condense it, a jet of cold water is made to play constantly inside the condenser, and the latter is kept cool by being surrounded with cold water. To effect this a pump, called the cold-water pump, is applied to the cistern in which the condenser is submerged. The cold water thus supplied has a tendency, from its comparative weight, to sink to the bottom, while the warm portion rises to the surface, and flows off through a waste-pipe. To remove the injected water, with the water resulting from the condensation of the steam, from the condenser, another pump is provided, called the air-pump, because it removes at the same time the air which enters in a fixed form with the water, and which is liberated by the heat of the steam. This air, if allowed to remain, would vitiate or destroy altogether the necessary vacuum. It is most necessary for the efficient operation of the engine, that the state of the vacuum in the condenser should be at all times known. For this purpose an indicator is adopted, called the barometer gauge, forming one of the most important appendages of the condensing steam-engine.

This instrument, as its name imports, is a common barometer; but the top of the tube, instead of being closed, is made to communicate with the condenser. The atmospheric pressure acting, as usual in barometers, on the mercury in the cistern, presses a column of mercury up the tube. If the vacuum in the condenser were as perfect as that which is at the top of the barometric tube, then the column of mercury in this instrument would stand at exactly the same height as in the common barometer; but as this is never the case, there is a difference of height which is due to the pressure of uncondensed steam and air, which, notwithstanding the action of the air-pump,

will always remain in greater or less quantity in the condenser. The difference, therefore, between the height of the column of mercury in the barometer gauge communicating with the condenser, and in a true barometer placed near it, will give, in inches of mercury, the pressure which reacts upon the piston against the steam. In well-kept engines, the barometer gauge is seldom more than 2 in. below the true barometer, which would give a pound to the inch for the pressure reacting on the piston. If the barometer gauge stand too low, it indicates the presence either of condensed vapour or of air in the condenser. This may arise either from too little or too much water being thrown in by the condensing jet. If too little be thrown in, the condensation will be imperfect, and uncondensed vapour will lower the gauge; if too much be thrown in, an accumulation of air will be produced faster than the pump can remove it, and the gauge will be similarly affected. The regulation of the jet is thus a matter which should be carefully attended to. The cock which regulates the jet has a handle to which an index is attached playing upon a divided scale; and according to the position of that index the cock is more or less open or closed.

The influence of the condenser upon the work of the engine is exerted in two different ways. In the first place, it acts by the extent of the partial vacuum which it offers to the steam to expand itself in; and, in the second place, by the cold water injected to condense the steam. There are therefore two principal points to be considered in applying a condenser to an engine. First, the extent of the partial vacuum, in other words, the capacity of the condenser and its inlet passages, relatively to the volume of the steam to be exhausted into it; and, second, the quantity of cold water to be injected according to the temperature of this water and the volume or weight of the steam and its temperature.

The following physical law constitutes the general principle according to which the former of these points is determined; namely, that when communication is established between two vessels each containing the same liquid, but at different temperatures, equilibrium of tension between the vapours which they emit takes place in the two vessels according to the tension corresponding to the vapour emitted by the colder liquid. Applying this law to steam-engine condensers, it may be observed that the condenser is almost wholly emptied of air, and contains only water, which emits steam capable of saturating the space, or at its maximum elastic force, whilst the other vessel, that is the cylinder, contains a large quantity of steam at a higher tension, but out of contact with the water which emitted it. This steam, on entering the condenser, expands like a permanent gas, according to the sum of the volumes of the cylinder and the condenser. Such, at least, is what takes place at the moment when the two are put into communication with each other; but as condensation begins at once, the tension is gradually reduced till finally it becomes equal to that of the steam emitted by the water in the condenser. It is true that to obtain this result there must at the same time be added the quantity of cold water necessary to take up the heat evolved by the steam in the act of condensation, otherwise this heat would be taken up by the water previously contained in the condenser, and the temperature of this water being thereby raised, the steam emitted would possess a degree of tension much greater than that which existed at the moment when the two vessels were placed in communication. Consequently, as the effect sought is really obtained only by the addition of cold water, which evidently requires a certain time to operate, it is a matter of practical importance to give the condenser such a capacity that the steam on entering may be greatly expanded even before condensation begins to take effect. These considerations lead us to conclude that the capacity of the condenser should not be less than one-third of the volume generated by the piston during a single stroke, and this conclusion is fully borne out by experiments and the practice of the best makers. Another rule, proposed by a French authority, is to make the volume of the condenser equal to three times that of the steam contained in the cylinder at the moment of being cut off, supposing the steam to have a tension of five atmospheres.

The second point, namely, the quantity of water to be injected, has been fully discussed under Details of Engines, to which article the reader is referred for information on this subject, as well as on that of the air-pump.

The use of the condenser is to reduce the back pressure on the piston, and, as this back pressure is exerted with equal force throughout the stroke, the gain is considerable. In an engine working with a pressure of five atmospheres and without expansion, a saving may be effected of one-fifth of the total work developed; and in an engine working under the same pressure, but with the steam cut off at one-fifth of the stroke, the economy may be as great as one-fourth. Thus it will be seen that in all cases the condenser is a source of economy varying in amount from 20 to 30 per cent., the greater amount being reached with high degrees of expansion. It may be remarked, however, that the difference between the barometric gauge and the barometer does not represent the actual gain of effective work; a portion of this gain is absorbed by the pumps, which are driven by the steam-piston. The first cost is also considerably enhanced, a matter deserving consideration when estimating the advantages of any system. The above results show, however, that when economy of fuel is important, the gain is sufficient to render the adoption of the condenser desirable wherever it can be conveniently applied.

The employment of steam expansively constitutes another notable source of economy, inasmuch as a very considerably larger proportion of work may be obtained from a pound of steam when used in this way. If, for example, we take an expansion of 10 times, the hyperbolic logarithm of 10 being 2·30, we see that the work developed upon the piston during the period of expansion is more than twice that which would have been developed by the same quantity of steam during admission. But it must not be forgotten that this increase of volume in the ratio of 1 to 10, increases in the same proportion the resisting action of the back pressure. This action must therefore be reduced as much as possible by the employment of the condenser. For this reason all engines in which a high degree of expansion is carried out should be condensing engines; the degree to which expansion may be carried out in a steam-cylinder is limited by practical considerations. It will be observed that the piston, which is urged by the force of expansive steam, is acted upon by a continually diminishing power of impulsion. When the pressure of the steam becomes, by expansion,

less than the load which such piston drives through the intervention of machinery, including the friction of the machinery itself, then it is clear that the moving force will cease to be efficacious, and that the piston must come to rest. The expedient by which the expansive principle may be most conveniently extended, is to use, at the beginning of the stroke, steam of high pressure and great density. This brings us to the consideration of another limit in a different direction. It is impossible with steam to have a change of pressure without a corresponding change of temperature, and this change of temperature is productive of a loss of power in an engine-cylinder. This loss may be thus explained. When the exhaust-valve is opened, the steam rushes to the condenser, and the vapour remaining in the cylinder, together with the condensed water adhering to its sides, are almost instantly cooled to the temperature of the condenser, and the surface of the cylinder is thereby cooled in a greater or less degree. The fresh steam, on entering for the next stroke, comes in contact with the previously cooled metal, and a portion of it is condensed without doing any work. This is repeated at every stroke, and in all engines is the source of a considerable loss of heat. This loss is necessarily greater, the greater the difference of temperature between the steam on entering and when being exhausted from the cylinder. When the degree of expansion is increased, the initial pressure must be increased also, and consequently steam of a higher temperature must be employed. The wider range of temperatures thus occasioned causes a greater loss of heat. There are two well-known expedients by which it is sought to lessen this loss, namely, the steam-jacket and superheating. The former acts by preventing, to some extent, the cooling of the cylinder; and the latter, by making the steam dry and a bad conductor, produces the same effect, while at the same time the condensation of the steam is prevented. These expedients diminish the loss of heat from the causes previously mentioned, but they do not prevent it altogether. As expansion is increased, the duty of the fuel is not increased at the rate shown by the theory of expansion. But, on the other hand, the loss of heat increases in a greater ratio than the gain of power due to expansion. Of course, as soon as the increase of loss balances the gain, economy can go no further. This limit is reached at different points, according to the different circumstances under which expansion is carried out.

To use high grades of expansion, and at the same time to avoid the loss of power resulting from the consequent wide range of temperatures, a method has of late years been adopted, and is now rapidly coming into favour, of expanding the steam in two cylinders. We shall return later to the consideration of this double-cylinder or compound engine.

The economy of fuel resulting from the employment of steam expansively is considerable. Speaking generally, this economy may be said to vary from 25 to 50 per cent. The theory of expansion, as well as several other questions relating to the production and employment of steam, has been fully treated of under Boilers, to which article the reader is referred.

A pound of coal consumed in the furnace of a steam-engine will produce a certain mechanical effect, and the amount or quantity of mechanical effect thus produced may be measured in foot-pounds, that is, by the number of pounds raised 1 ft. high. This effect is called the *duty* of the fuel, or more usually, the duty of the engine. The duty of an engine is therefore not the amount of work developed by the fuel in producing evaporation, but only that portion of the total work developed by the steam which is available for the work to which the engine is applied, the difference being absorbed by the engine itself. The duty of engines varies within very wide limits. In some instances in which expansion and condensation are carefully and intelligently carried out, we find a consumption of 1·5 lb. of coal to the horse-power an hour; in others the consumption is as much as 7 or 8 lbs. The duty of a Cornish pumping engine is usually estimated in pounds of water lifted 1 ft. high by the consumption of a bushel of coals. As high a duty as 125 millions of pounds has been reached by this class of engines. Such results must, however, be regarded as altogether exceptional. The more common duty obtained from a well-managed engine used in the mining districts is from 65 to 75 millions. The duty of an engine is not to be confounded with its *power*. The duty, as we have seen, is the work developed by a given weight of coals without reference to time. Thus, whether a bushel of coal raises 70 millions of pounds a foot high in one hour or in twelve hours, the duty of the engine is the same. But the power of the engine is quite different, being estimated by the work it is capable of performing in a given time. Hence, while the duty of the engine is measured by the number of pounds raised 1 ft. high, its power is measured by the number of pounds raised 1 ft. high in one minute. To avoid the large numbers involved in this mode of estimating the power of an engine, it is customary to express it in terms of the higher unit horse-power, which represents the power requisite to raise 33,000 lbs. 1 ft. high in one minute. Thus an engine of 10 horse-power is capable of raising 330,000 lbs. 1 ft. a minute, or about 20 millions of pounds an hour. This is known as *effective* horse-power, to distinguish it from *nominal* horse-power, the latter being a term somewhat capriciously employed by makers to express certain cylinder capacities and dimensions. In determining the dimensions of a boiler for a stationary engine other than the Cornish engine it is customary to assume that for every effective horse-power to be exerted by the engine, 1 cub. ft. of water an hour must be evaporated by the boiler. This allows a very large percentage of waste in the engine, greater probably than ever takes place; but the error is on the safe side, and the rule may be considered as sufficiently accurate in practice. When, therefore, the term horse-power is applied to boilers, it is to be understood as indicating their capability of evaporation at the rate of a cubic foot of water an hour. Thus a boiler of 50 horse-power is one capable of evaporating 50 cub. ft. of water an hour, the furnaces being worked in the ordinary way. The dimensions of the grate and the extent of heating surface necessary to produce this rate of evaporation vary more or less according to the practice of different engineers; but generally it is agreed that 1 sq. ft. of grate surface is requisite for every horse-power in the boiler. Thus it follows that as much fuel is consumed an hour upon a square foot of grate surface as is necessary and sufficient to evaporate a cubic foot of water. The extent of heating surface in the boiler is generally estimated at the rate of 15 sq. ft. to the horse-power. Thus a boiler of 50 horse-power requires a heating surface of 750 sq. ft. In the Cornish boiler, on

account of the slow combustion maintained on the grates, 2 sq. ft. of the latter are allowed to the horse-power, and the extent of heating surface is increased four or five times.

In proportioning the dimensions of the cylinder, it is usual in stationary land engines to make the diameter equal to twice the stroke of the piston. With respect to the absolute dimensions, it is obvious that the magnitude of the cylinder and piston necessary to produce a given power must depend upon the pressure of the steam after it has entered the cylinder and the velocity with which the piston moves, the degree of vacuum on the other side of the piston, and the grade of expansion carried out. When the piston and other reciprocating parts of the machinery change the direction of their motion at the end of each stroke, they will be, for a short interval, before and after the change, accelerated and retarded. This acceleration and retardation is still greater when the steam is used expansively, since, in that case, the impelling power varies in intensity. In practice, however, the irregularity is effaced by the momentum of the fly-wheel, and we may assume for the purposes of calculation that the motion of the piston is uniform. The question which then remains is, what determines the rate of this uniform speed? In other words, what are the conditions that determine whether the piston shall have a velocity of 100 or 200 ft. a minute? The velocity of the piston will depend upon the rate at which the boiler is capable of supplying steam of the requisite tension to the cylinder. Suppose, for example, that the resistance on the piston is equal to a pressure of 20 lbs. to the square inch of its surface. To drive the piston at any given rate, the boiler must be capable of supplying steam at a tension of 20 lbs. in sufficient quantity to fill the space swept through by the piston in a given time. As an illustration, let us assume that the required speed is 200 ft. a minute and that the area of the piston is 78·5 sq. in., corresponding to a diameter of 10 in., which, expressed in square feet $= \cdot 545$. Then to enable the piston to advance through a space of 200 ft., it must be followed by a column of steam 200 ft. in length and ·545 sq. ft. in section, which equals 109 cub. ft. of steam. But the relative volume of steam at a pressure of 20 lbs. as compared with the water from which it is produced, is that of 1222 to 1. Dividing, therefore, we have $\frac{109}{1222} = \cdot 089$. The boiler must thus be capable of evaporating $\cdot 089 \times 60 = 5 \cdot 34$ cub. ft. of water an hour. That is, allowing a margin for the increased resistance due to the speed, the boiler must be of 6 horse-power.

Total Pressure in lbs. per square inch.	Corresponding Temperature.	Relative Volume, or cubic inches of Steam produced by a cubic inch of Water.	Total Pressure in lbs. per square inch.	Corresponding Temperature.	Relative Volume, or cubic inches of Steam produced by a cubic inch of Water.	Total Pressure in lbs. per square inch.	Corresponding Temperature.	Relative Volume, or cubic inches of Steam produced by a cubic inch of Water.
1	102	20404	39	265·9	652	76	310·5	348
2	126	10646	40	267·4	637	77	311·4	344
3	142	7615	41	268·9	622	78	312·4	340
4	153	5549	42	270·4	608	79	313·2	336
5	162	4499	43	271·9	595	80	314·1	332
6	170·3	3790	44	273·3	582	81	315·0	327
7	176·9	3279	45	274·7	570	82	315·9	324
8	182·8	2892	46	276·1	558	83	316·7	320
9	188·1	2595	47	277·5	547	84	317·6	317
10	192·9	2345	48	278·8	537	85	318·4	314
11	197·4	2144	49	280·1	526	86	319·3	310
12	201·6	1976	50	281·4	516	87	320·1	307
13	205·5	1832	51	282·7	507	88	321·0	304
14	209·2	1709	52	284·0	498	89	321·7	300
15	212·7	1602	53	285·2	489	90	322·5	297
16	215·9	1508	54	286·4	480	91	323·3	294
17	219·1	1424	55	287·6	472	92	324·1	291
18	222·0	1311	56	288·8	464	93	324·9	288
19	224·9	1282	57	290·0	457	94	325·7	285
20	227·6	1222	58	291·1	449	95	326·5	282
21	230·2	1167	59	292·3	442	96	327·2	279
22	232·8	1118	60	293·4	435	97	328·0	277
23	235·2	1072	61	295·5	427	98	328·8	274
24	237·6	1030	62	296·6	422	99	329·5	271
25	239·8	991	63	297·6	416	100	330·2	269
26	242·0	955	64	298·7	409	110	337·3	246
27	244·2	922	65	299·8	404	120	343·9	227
28	246·2	891	66	300·8	398	130	350·1	210
29	248·3	862	67	301·8	389	140	355·9	196
30	250·2	835	68	302·8	387	150	361·4	183
31	252·1	810	69	303·8	381	160	366·6	173
32	254·0	786	70	304·8	376	170	371·6	163
33	255·8	763	71	305·8	371	180	376·3	155
34	257·6	742	72	306·8	367	190	380·8	147
35	259·3	722	73	307·7	362	200	385·2	140
36	261·0	703	74	308·7	357	250	403·5	114
37	262·7	685	75	309·6	353	300	421·0	100
38	264·3	668						

By means of the foregoing Table many practical problems similar to the preceding and of great utility, may be solved with the aid of common arithmetic alone. The temperatures corresponding to the pressures from 1 to 5 lbs. are taken from Rankine; the whole of the remaining quantities we have carefully calculated. They will be found to vary somewhat from those of similar tables that have been published; but it is believed that they are more accurate, the formulæ by which they were calculated being fully confirmed by the elaborate calculations of Zeuner and Rankine respecting the relation existing between the latent heat of evaporation, the temperature, and the specific volume of steam.

The following examples illustrate the use of the preceding Table:—

1. A boiler is capable of evaporating 20 cub. ft. of water an hour. The pressure of steam in the cylinder being 20 lbs., what must be the diameter of the cylinder to give a piston speed of 200 ft. a minute?

By referring to the Table, we find the relative volume for 20 lbs. to be 1222. Hence $\frac{1222 \times 20}{60} = 407 \cdot 3$ is the number of cubic feet of steam that will pass through the cylinder a minute, and $\frac{407 \cdot 3 \times 144}{200} = 293 \cdot 2$ sq. in. = the area of the piston. A table of areas will at once give the diameter.

2. A piston 20 in. in diameter is required to move with a velocity of 200 ft. a minute against a gross resistance of 10,000 lbs.; it is required to find the requisite boiler power.

A table of areas gives 314·1 sq. in. for a diameter of 20 in. As the resistance is 10,000 lbs., the pressure to the square inch will be $\frac{10000}{314 \cdot 1} = 31 \cdot 8$ lbs. The next greater pressure to this in the Table is 32, the relative volume corresponding to which is 786. The area of the piston in square feet being 2·181, the power of the boiler $= \frac{2 \cdot 181 \times 200 \times 60}{786} = 31 \cdot 77$, say 32 horse-power.

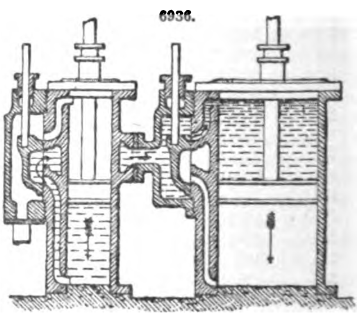
3. Given a piston 30 in. in diameter, supplied by a boiler of 50 horse-power, it is required to find the pressure to the square inch that can be given to the piston when the latter has a velocity of 200 ft. a minute.

The area of the piston is 706·8 sq. in. = 4·908 sq. ft. Hence $\frac{4 \cdot 908 \times 200 \times 60}{50} = 1177 \cdot \dot{9}$, the number of cubic inches of steam that would be produced by a cubic inch of water. The nearest number to this in the Table is 1167, and the pressure corresponding to this number is 21 lbs. We may therefore assume that the required pressure is $20\frac{3}{4}$ lbs.

4. Given a piston 40 in. in diameter, and a boiler of 50 horse-power; it is required to find at what velocity the piston may be driven against a resistance of 20 lbs. to the square inch. For a pressure of 20 lbs. the Table gives 1222 as the relative volume. Hence $1222 \times 50 = 61100$ is the number of the cubic feet of steam that passes through the cylinder an hour. The area of the piston in square feet being 8·72, we have $\frac{61100}{8 \cdot 72 \times 60} = 116 \cdot 8$, say 116 ft. a minute.

The compound system of engine, to which we have already alluded, consists essentially in passing the steam through two cylinders of unequal dimensions, the second and larger serving as a kind of receiver to the first, the steam from which it uses a second time by expansion. It was to realize more effectually the principle of expansion that the system was first introduced, and the success which has been attained is such as to render it one of the greatest improvements of recent years. And it is not difficult to discover the cause of this success. We have already described the ill effects of a wide range of temperatures, or, which is the same thing, a wide range of pressures in one cylinder. By carrying out the expansion in two cylinders, these ill effects are diminished in a considerable degree. Also when a high grade of expansion is carried out in one cylinder, the variation of pressure necessitates relatively larger dimensions in the parts through which the force is transmitted, and, moreover, produces an irregular velocity which can be modified only by means of a heavy fly-wheel. By using two cylinders, the pistons of which work together with different pressures, the inequality of the strains is certainly not altogether avoided, but it is greatly diminished. Thus the objections to very high grades of expansion are by this means, to a considerable extent, removed.

6936.



The invention of the compound engine is due to Hornblower, who first made the system known in the year 1781. It was not, however, carried into effect till more than twenty years later, by Woolf, under whose name it was for a long time known. Recent years have witnessed considerable improvements in this class of engine, chief among which must be reckoned the construction of engines with the two cylinders connected to cranks at or near right angles to each other, and the placing of a receiver between the two cylinders.

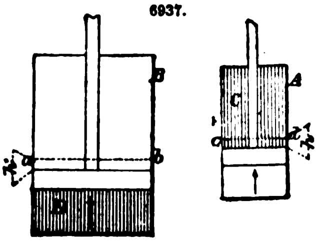
In the accompanying diagram, Fig. 6936, which we have introduced for the purpose of explaining the action of the compound engine, we have supposed, in order to make the course of the steam apparent to the eye, that the exhaust-passage from the small cylinder passes round it, and directly into the valve-box of the large cylinder. The piston of the small cylinder is driven by the steam from the boiler in the same way as in a single-cylinder engine, and either with or without expansion. When the stroke of the piston in either

direction is completed, the steam, instead of escaping into the atmosphere or into the condenser, is conducted into the valve-box of the large cylinder, whence it exerts its pressure simultaneously upon the two pistons. As these pistons are connected to the same crank-shaft, they complete their stroke together, so that all the steam from the small cylinder passes into the large one. Consequently, supposing for the sake of simplicity that the steam is not expanded in the small cylinder, it is expanded in the ratio of the volumes generated by the two pistons, and this ratio marks the degree of expansion carried out. At the next stroke the same effects are produced in the contrary direction, and the former cylinder full of steam is exhausted into a condenser in the usual way.

In the figure both pistons are supposed to be descending. The steam from the boiler enters above the small piston, whilst that beneath it, and by which it was raised at the preceding stroke, passes out and enters above the large piston, the lower portion of the large cylinder being then in communication with the condenser, in which the steam is exhausted that had entered from above the small piston. In most beam-engines the two pistons move in the same direction. In such a case, the steam-passages cross, that is, the steam passes from beneath the small piston to enter above the large one, and the reverse. But when the motion of the pistons is in contrary directions, the steam-passages are direct, that is, on issuing from the small cylinder it enters directly into the corresponding end of the large cylinder. Such details, however, in no way affect the general principle.

The pistons may be either equal or unequal in stroke or in area, but an essential point is that they must generate different volumes. It is an interesting fact that the work developed by a given volume of steam is exactly the same whether expanded in one cylinder or in two. This fact is clearly proved by the following simple means, proposed by Poncelet. It has already been shown that the absolute quantity of work generated by a given volume of steam by expansion is measured by the increase of volume which it has acquired and by the initial pressure. This being true for the total increase of volume and the total quantity of work, is not less true for each partial increase of volume which develops a partial quantity of work, the measure of which is also this increase of volume and the mean pressure at the moment when it takes place. Suppose, then, two cylinders, A and B, Fig. 6937, in which the two pistons advance simultaneously by a certain quantity. If we take an instant when the steam is confined in the spaces C and D, and if in passing from C to D the pistons advance by infinitely small quantities h and h' respectively, the steam develops in the same time upon the large piston a certain quantity of work, which quantity must be diminished by that generated as resistance to find the expression of the work really effective. The value of the work developed in the two cases is evidently the product of the area of the piston by the space through which it has moved and by the pressure of the steam, which at any given instant of time is the same in both cylinders, since they are in communication with each other. Therefore, representing the area of the large piston by S, the extent of its forward motion by h', the area of the small piston by s, the extent of its forward motion by h, and the common and mean pressure on the unit of surface during this infinitesimally small extent of forward motion of the two pistons by P, the quantity of work developed during this forward motion of the pistons is,

6937.



$$(P \times S \times h') - (P \times s \times h) = P(S h' - s h).$$

But the factor $S h' = s h$ is the exact expression of the increase of volume of the steam at the moment considered; therefore each partial quantity of work developed by the steam is proportional to its partial increase of volume; which it was required to prove.

Thus, whether we make use of two cylinders or one, the quantity of work will be the same for a given degree of expansion, the initial pressure being, of course, the same in both cases. And this is evidently independent of the stroke or the diameters of the pistons. We may therefore, without going into further particulars, state that in determining the dimensions of the cylinders of a Woolf engine the volume generated by the large piston is equal to that of the single cylinder for the same power, the same degree of expansion, and the same initial pressure, and that the volume generated by the small piston is equal to that of the steam before expansion, supposing expansion to be carried out wholly in the large cylinder. In other words, the ratio of the volumes generated by the two pistons is simply the degree of expansion carried out, when expansion is not begun in the small cylinder. In the contrary case, the ratio of these two volumes becomes the quotient of the degree of total expansion divided by the expansion effected in the small cylinder; but the volume of the large cylinder is invariable, whether expansion be carried out in it alone or in both, the small cylinder only being affected by the latter condition.

With respect to the back pressure in a compound engine, other things being equal, this pressure produces a resisting force measured by the volume which is generated by the piston upon which it acts. But as the large piston of a double-cylinder engine generates precisely the same total volume as that of a single-cylinder engine working with the same degree of expansion, the back pressure produces the same amount of resistance in both cases. Consequently, compound engines are calculated in precisely the same manner as ordinary single-cylinder engines worked with expansion.

A very ready method of making, by means of a Table, the requisite calculations relating to the expansive action of steam in either single or double cylinders has been proposed by David Thomson, in a paper recently read before the Association of Foremen Engineers. As this Table will be found of very great use to practical men, we give it, with a few of the author's remarks thereon, which will elucidate some of the questions respecting compound engines in which opinions are divided.

Steam Worked Expansively.

Table of Mean and Initial Pressures in the Cylinder. On the supposition that the pressures are inversely as the volumes.

Points of Cut-off in fractions of the Stroke, reckoned from the beginning.	Degrees of Expansion, or number of times the Steam is expanded.	Hyperbolic Logarithms of the Degrees of Expansion.	Mean Pressures during the Stroke, the initial pressures being taken as 1.	Initial Pressures in Cylinder, the mean pressures being taken as 1.
$\frac{3}{4}$	$1\frac{1}{3}$	·2876	·965	1·036
$\frac{7}{10}$	$1\frac{3}{7}$	·3506	·949	1·054
$\frac{2}{3}$	$1\frac{1}{2}$	·4055	·937	1·067
$\frac{6}{10}$	$1\frac{2}{3}$	·5108	·904	1·106
$\frac{1}{2}$	2	·6931	·846	1·182
$\frac{4}{10}$	$2\frac{1}{2}$	·9163	·766	1·305
$\frac{1}{3}$	3	1·0986	·669	1·495
$\frac{3}{10}$	$3\frac{1}{3}$	1·2040	·661	1·513
$\frac{1}{4}$	4	1·3863	·596	1·678
$\frac{2}{10}$	5	1·6094	·522	1·916
$\frac{1}{6}$	6	1·7918	·465	2·105
$\frac{1}{7}$	7	1·9459	·421	2·375
$\frac{1}{8}$	8	2·0794	·385	2·598
$\frac{1}{9}$	9	2·1972	·355	2·817
$\frac{1}{10}$	10	2·3025	·330	3·030
$\frac{1}{11}$	11	2·3979	·309	3·236
$\frac{1}{12}$	12	2·4849	·290	3·448
$\frac{1}{13}$	13	2·5649	·274	3·649
$\frac{1}{14}$	14	2·6391	·260	3·846
$\frac{1}{15}$	15	2·7081	·247	4·048
$\frac{1}{16}$	16	2·7726	·236	4·237
$\frac{1}{17}$	17	2·8332	·226	4·425
$\frac{1}{18}$	18	2·8904	·216	4·629
$\frac{1}{19}$	19	2·9444	·208	4·807
$\frac{1}{20}$	20	2·9957	·200	5·000
$\frac{1}{21}$	21	3·0445	·192	5·208
$\frac{1}{22}$	22	3·0910	·186	5·376
$\frac{1}{23}$	23	3·1355	·180	5·555
$\frac{1}{24}$	24	3·1781	·174	5·747
$\frac{1}{25}$	25	3·2189	·169	5·917

"I now proceed to show how the calculations connected with compound and other expansive engines may be made with ease and rapidity by means of the Table. These calculations are often made by means of diagrams of expansion, or expansion curves, drawn on the same principles on which this Table is calculated, but I have always found such calculations to be made more rapidly and accurately by means of a table than a diagram.

"When steam is expanded in the cylinder of a steam-engine its pressure at any part of the stroke is very nearly inversely proportional to the volume it occupies. This is not *exactly* the case, but very nearly so, and in almost all indicator diagrams it is found that the pressure is slightly greater than it ought to be by this rule. If, therefore, the size of a cylinder is calculated on the supposition that the pressure of the expanding steam is inversely as the volume, a slight error may be expected on what engineers often call the 'right side'—that is, the size will be slightly above what is strictly required.

"The Table is calculated on the supposition that this rule is accurate. To give an example of its application, let it be required to find the area of a cylinder to yield 100 I H P., with a maximum pressure of steam of 60 lbs. above the atmosphere, an expansion of six times, back pressure 2 lbs. per square inch, and a piston speed of 300 ft. per minute.

"Here the average pressure required on the piston to give this power $= \frac{33000 \times 100}{300} = 11000$ lbs.

Next, maximum pressure of steam above the atmosphere = 60 lbs.
Add pressure of atmosphere .. .. 15 „

Maximum total pressure .. .. 75 lbs.

"Referring to the Table, in the line for six times expansion, we find that in these circumstances the average pressure over the whole stroke .. .. $= 75 \times ·465 = 34·875$ lbs.
Deduct back pressure .. .. 2·000 „

And we have the mean effective pressure over the whole stroke .. $= 32·875$ lbs.

"From which it follows that the area of the piston $= \frac{11000}{32·875} = 335$ sq. in., and a table of areas of circles gives the diameter of the cylinder $= 20\frac{3}{4}$ in.

"When a high degree of expansion is effected in one cylinder, the maximum strain on the crank-pin is much larger than the average working pressure over the length of the stroke, as is very

clearly shown by a reference to the Table. To diminish this excessive strain is the object sought in employing two cylinders to work conjointly, the one receiving the steam from the other, and thus forming what we call a compound engine.

"If, in the example we have taken, the six times expansion had been carried out in two cylinders, the mechanical effect developed would have been exactly the same; and so also would have been the final pressure. It is readily seen that if the final pressure is the same in both cases, and the quantity of steam used is also the same, the capacity of the large cylinder of the compound engine must be the same as that of the single-cylinder engine of the same power, and working with the same degree of total expansion. All that is necessary, therefore, in calculating the size of the large cylinder for a compound engine is to calculate, in the way we have already done, the size of a single cylinder to develop the required power with the given initial pressure and the given amount of expansion. This will be the size required for the large cylinder of a compound engine to develop the given power; and the only use of adding a small cylinder to it is to moderate the maximum strain on the crank-pin, and give a more equable development of power over the whole stroke of the piston. This being the object aimed at, it is best to make the size of the small cylinder such that the maximum strain on the crank-pin shall be the smallest possible under the given conditions. Dr. Pole, in a paper on Compound Engines, shows, for the Woolf form of engine, that this is effected by making $\frac{\text{Area of large cylinder}}{\sqrt{\text{Degree of expansion}}}$ = area of small cylinder.

"The rule applied to the example we have already taken would give

$$\text{Area of small cylinder} = \frac{335}{\sqrt{6}} = 137 \text{ sq. in., and}$$
$$\text{Diameter} = 13\tfrac{1}{4} \text{ in.}$$

"The area of the small cylinder being thus calculated, it is to be understood that to get the best result half the expansion is to be effected in the small cylinder, and the remainder during expansion into the large cylinder. Thus, in the present instance, the steam is to be expanded 2·449 times in each cylinder, and $2{\cdot}449 \times 2{\cdot}449 = 6$; making six times expansion in all.

"For the *marine* compound engine the area of the small cylinder is not so definitively fixed; because the two pistons, acting on different cranks, the object generally is to make the maximum strain of either taken singly a minimum. And besides, the maximum strains of either piston can be considerably varied by altering the point of cut-off in the large cylinder. Nevertheless Dr. Pole's rule for Woolf engines will be found generally to give good results for the other form of engine also, and such as fairly correspond with the best practice. The assertion that the mechanical power developed is the same whether the expansion takes place in one or two cylinders, requires this qualification, that when two cylinders are used the arrangements must be such that none of the expansion takes place uselessly, by the steam rushing into the passages and so causing a sudden drop of the pressure, without doing any work on the piston. In the Woolf form of compound engine this condition has not hitherto been absolutely complied with, and in some engines of this type it is very far from being so. A considerable loss of effect is the consequence.

"The amount of this will be seen if we take an example, thus—

"Let the capacity of the small cylinder be = 4; capacity of the large one = 16; and the capacity of the steam-passage between them = 1, or the fourth part of the small cylinder. Suppose, further, that the maximum *total* pressure of the steam in the small cylinder = 75 lbs., and that it is cut off at $\frac{1}{3}$ stroke. With these data the expansion should be, if we disregard the effect of the intermediate passage, three times in the small cylinder, and four times more in expanding into the large one; or $3 \times 4 = 12$ times. But the actual operation would be this—

"First the steam would be expanded three times in the small cylinder, thus reducing the pressure to $\frac{75}{3} = 25$ lbs. On the exhaust-valve being opened the steam would rush out into the intermediate passage, and thus occupy a space $= 4 + 1 = 5$, by which its pressure would be reduced to $25 \times \frac{4}{5} = 20$ lbs.; and this part of the expansion being uselessly expended in friction and producing no motion in the pistons, would be productive of no useful effect. It is assumed here and in what follows that the passage is entirely empty. This should not be the case, for it should be filled with steam of a pressure equal to the *final* working pressure in the large cylinder. In practice, however, the drop of pressure is generally quite as great as it ought to be, on the supposition of the passage being empty, and if the theoretical effect of the supposed small steam pressure existing in the passage were taken account of in these calculations, it would only complicate them, without producing any difference of practical consequence in the results arrived at.

"The steam which now occupies a space = 5 will, at the end of the large cylinder stroke, occupy a space $= 16 + 1 = 17$; thus having been expanded $\frac{17}{5} = 3\frac{2}{5}$ times during its passage into the large cylinder. The total effective expansion in both cylinders is therefore $= 3 \times 3\frac{2}{5} = 10\frac{1}{5}$ times, instead of 12 times, which it would have been but for the effect of the intermediate passage. The loss of efficiency thus caused is measured by the difference between

$$1 + \text{Hyperbolic log. } 12, \text{ and}$$
$$1 + \text{Hyperbolic log. } 10\tfrac{1}{5};$$

that is, it amounts to $1 - \frac{3{\cdot}322}{3{\cdot}485} = 1 - {\cdot}953 = {\cdot}047$, or nearly 5 per cent., of the whole efficiency of the steam when expanded twelve times in one cylinder. In many Woolf engines the loss of efficiency from this cause is greater than this; but it need not be so if the engines are well constructed; and this defect may be diminished or entirely removed if Woolf engines were made

with intermediate receivers, and the steam cut off at the proper point of the stroke in the large cylinder, as is done in the modern marine engines.

"Some of the best of these are worked in this way—that is to say, so as to have no, or almost no drop of pressure, at the end of the small cylinder diagram. But even where this is not the case, I propose to show that a comparatively large fall of pressure at this point may take place in a compound engine with an intermediate receiver without producing so great a loss of efficiency as a much smaller drop in the old form of Woolf engine.

"This may be done without intricate mathematical formulæ by the aid of the Table and by taking a particular example, the reasoning applied to which will be seen at each step to be equally applicable to *any* example that can occur in practice.

"Further to simplify the calculations, without affecting the deductions to be drawn from them, I assume the area of the small cylinder to be 1 sq. in., the area of the large cylinder = 4 sq. in., and the stroke of both = 1 ft.

"Let the capacities of the cylinders be reckoned in units of 1 in. square by 1 ft. long, and then we shall have

Capacity of small cylinder = 1
„ of large ditto = 4

"Let the steam be cut off at $\frac{1}{4}$ stroke in small cylinder, and then

Total expansion = 16 times.

"Further suppose the maximum total pressure of the steam in the small cylinder = 160 lbs. Then we shall have

$$\text{Pressure in small cylinder at end of stroke} = \frac{160}{4} = 40 \text{ lbs.}$$

$$\text{„ in large cylinder at end of stroke} = \frac{160}{16} = 10 \text{ lbs.}$$

"By means of a cut-off valve in the large cylinder, the pressure maintained in the reservoir may be regulated at pleasure; and for the sake of simplicity let it be assumed that the reservoir is sufficiently large to make the pressure in it practically uniform.

"Now let us calculate the indicated power developed in three different cases, in all of which the quantity of steam used per stroke is the same, *viz.*:—

"1st. If the steam is expanded 16 times in the large cylinder only, working as a single-cylinder engine having the steam cut off at $\frac{1}{16}$ stroke.

"2nd. If the total expansion of the steam is effected in two cylinders as I have described, and with the pressure in the reservoir maintained at 40 lbs.

"3rd. Ditto, ditto, but with the pressure in the reservoir maintained at 20 lbs.

"*1st Case.*—Power developed per half stroke = 160 × ·234 × 4 = 151 ft. lbs.

"*2nd Case.*—In this case it will be observed that there is no drop of pressure at the end of the small cylinder diagram, because the final steam pressure in the small cylinder is equal to that in the reservoir; and the power developed in each cylinder is—

Power developed in small cylinder per half stroke = 160 × ·596 − 40 = 55·56 ft. lbs.
„ „ in large cylinder „ „ = 40 × ·596 × 4 = 95·36 „ „

Total power developed in both cylinders per half stroke = 150·72 ft. lbs.

"This it will be seen is identical with the power developed in a single cylinder in accordance with the general principles I have already explained, as applying where, as in this case, there is no useless expansion without doing work on the piston.

"*3rd Case.*—In this case there is a large fall of pressure in the small cylinder diagram at the end of the stroke from 40 to 50 lbs., and the calculation of the power developed is—

Power developed in small cylinder per half stroke = 160 × ·596 − 20 = 75·36 ft. lbs.
„ „ in large cylinder „ „ = 20 × ·846 × 4 = 67·68 „ „

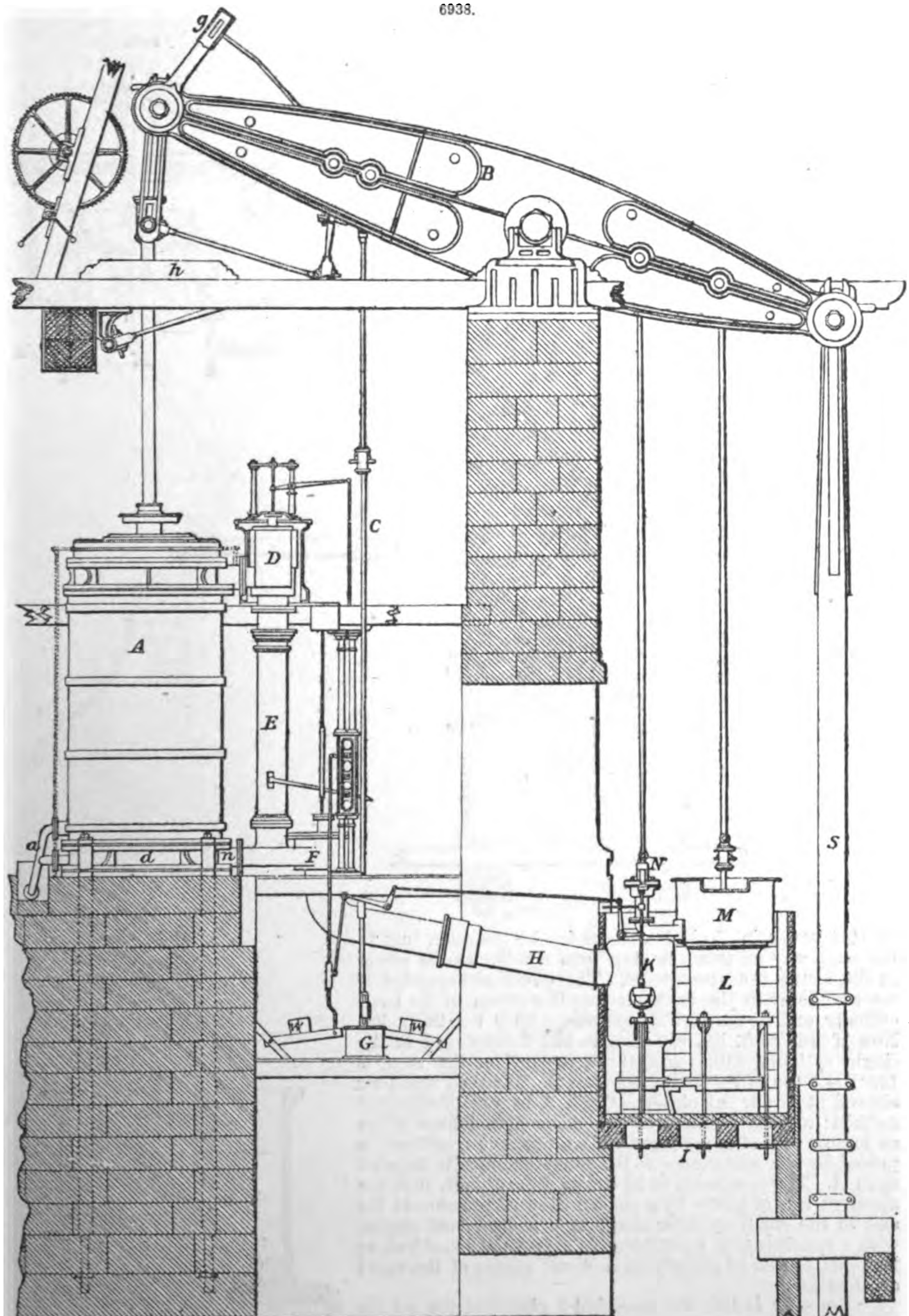
Total power developed in both cylinders per half stroke = 143·04 ft. lbs.

"This last result is, as anticipated, smaller than the two former ones, but it is not nearly so much smaller as the large drop of one-half in the pressure at the end of the small cylinder diagram might have led one to expect. It is only a diminution of 5 per cent. in the efficiency of the steam; whereas we saw before that a drop of only one-fifth of the pressure at the end of the stroke in the small cylinder of a Woolf engine produced a loss of efficiency of nearly the same amount.

"Let us look at the matter from another point of view. In case 3 the steam is expanded *effectively* four times in the small cylinder, after which it is further expanded twice by an instantaneous drop of the pressure on exhausting it into the receiver. It expands, in fact, into double its volume, and the pressure falls from 40 to 20 lbs., and in doing so it exerts no power on the piston, which has been sensibly stationary during the expansion. After this the steam is admitted to the large cylinder at 20 lbs. pressure, is cut off at $\frac{1}{2}$ stroke, and then expands during the remainder of the stroke, down to its final pressure of 10 lbs. at the end of the stroke. This last expansion has done its proper work on the large piston, and this, with the previous *effective* expansion in the small cylinder, makes a total effective of 4 × 2 = 8 times only; as compared with the total expansion of 16 times, *viz.* from pressure of 160 lbs. down to 10 lbs. It would seem at first sight that the efficiency of the steam would in this case be the same as if it had been expanded eight times in one cylinder. To expand the *same quantity* of steam in one cylinder, the capacity of the cylinder must be = 2, and the steam must be cut off at $\frac{1}{8}$ of the stroke. Then power developed = 160 × ·385 = 123·2 ft. lbs.

"This result is very considerably less than we obtained before in the calculation of the 3rd case, where it was shown that power = 143 ft. lbs. was developed. Yet in both cases the quantity of steam is the same, and apparently the amount of expansion exerted *usefully* on the pistons is the same in both; and the question arises, how can the steam, when expanded in the two cylinders, give a greater useful effect than when expanded in one?

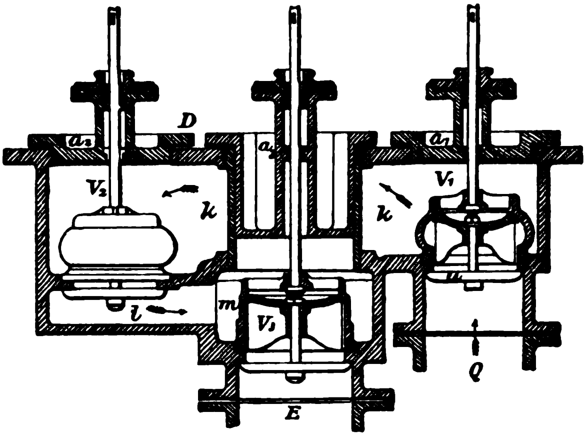
6938.



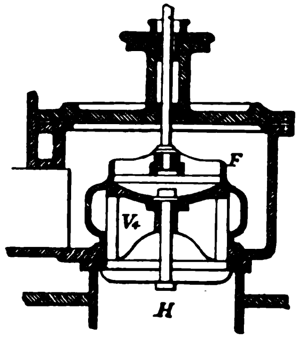
"The answer to this question is to be found in the consideration of what is done by the steam when it is exhausted from the small cylinder into the receiver. Previous to the opening of the exhaust-valve the steam occupies a bulk = 1 in the small cylinder at a pressure of 40 lbs.; and when the valve is opened, it at once expands till the pressure is reduced to that of the reservoir, 20 lbs.; after

this there will be left in the small cylinder the same bulk (1) of steam as before, but only one-half the *quantity*; inasmuch as the pressure is now 20 lbs. instead of 40 lbs., as it was before the exhaust took place. One-half the steam, therefore, has been discharged from the cylinder, and now occupies a bulk of 1 in the reservoir, at a pressure of 20 lbs. In gaining this position it has necessarily

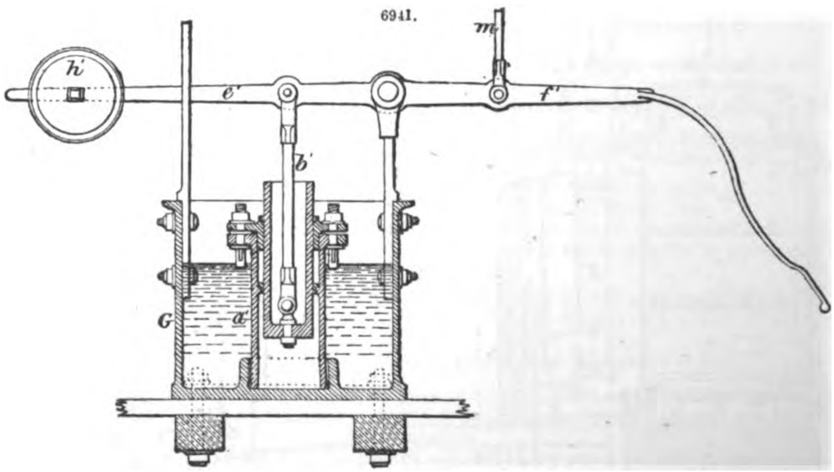
6939.



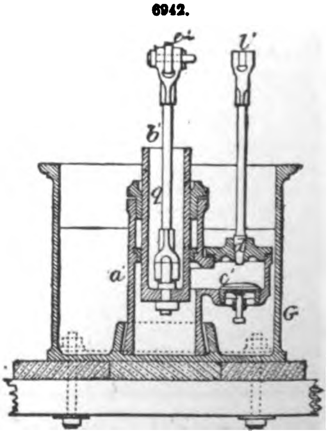
6940.



6941.



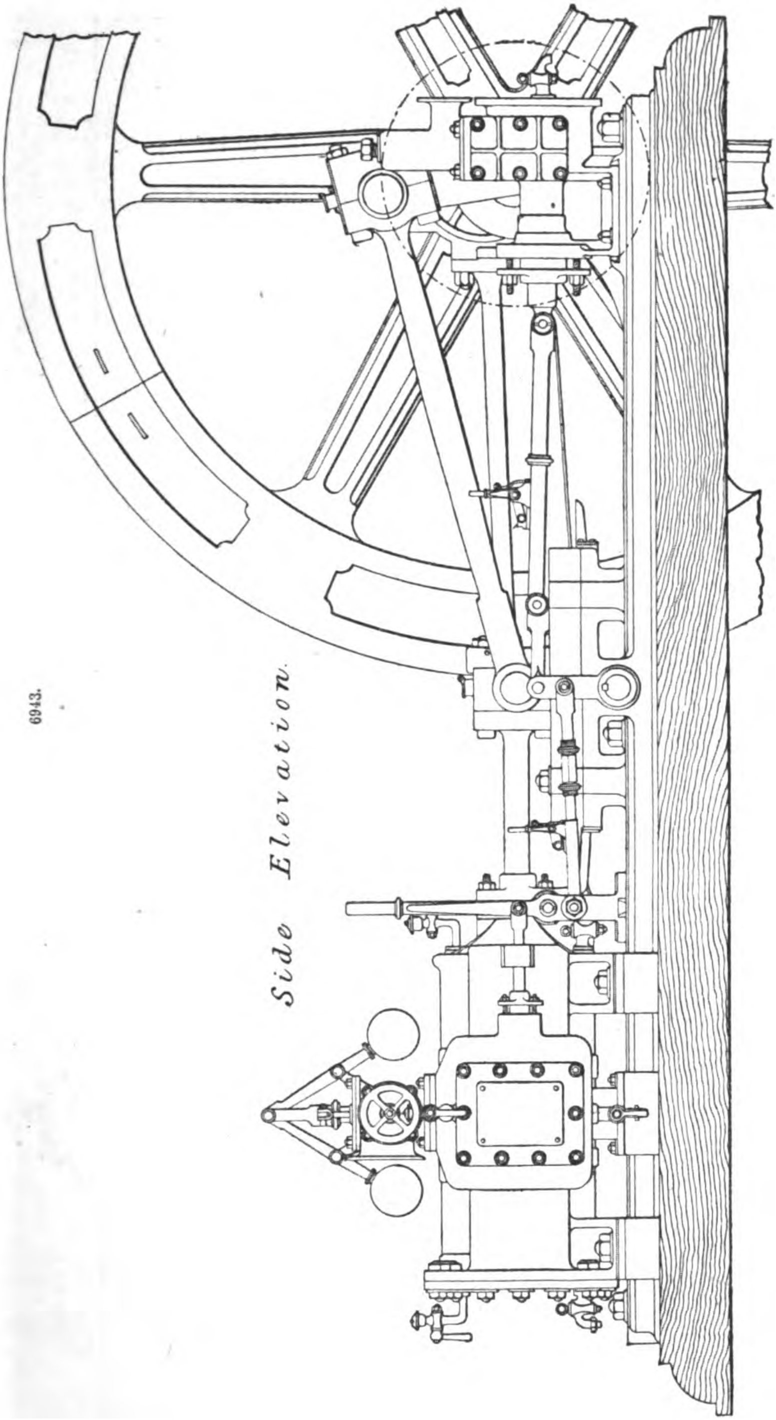
6942.



exerted power in displacing steam in the reservoir, just in the same way as steam issuing from a boiler exerts power in displacing the atmosphere. The power so expended is recoverable when the reservoir supplies steam to the large cylinder, and its amount in this case = 20 × 1 = 20 ft. lbs. Now if this 20 ft. lbs. is added to 123·2 developed in the single cylinder with eight times expansion, the sum is 123·2 + 20 = 143·2 ft. lbs., which is the identical result we arrived at in our calculation of case 3, by an independent method; and the accuracy of the explanation I have given as to how part of the apparently lost power is recovered, is proved by the correctness of the numerical results founded upon it. The conclusion to be drawn from this is, that the apparent loss of power by a sudden drop of pressure at the end of the small cylinder diagram in a compound engine with a reservoir is to a considerable extent not a *real* loss, as it would be almost entirely in a Woolf engine of the usual construction.

"Not only is this the case, but a glance at the results we obtained in calculating the power developed in each cylinder in cases 2 and 3 shows that when the engine is working with this great drop in the pressure, and thus incurring a loss of 5 per cent. of the gross indicated power, the division of work between the two cylinders is much more equal than when working without it.

"A slight consideration would also show that the maximum strains on the cranks are much less when thus working; and therefore, owing to the diminished friction and more moderate strains,

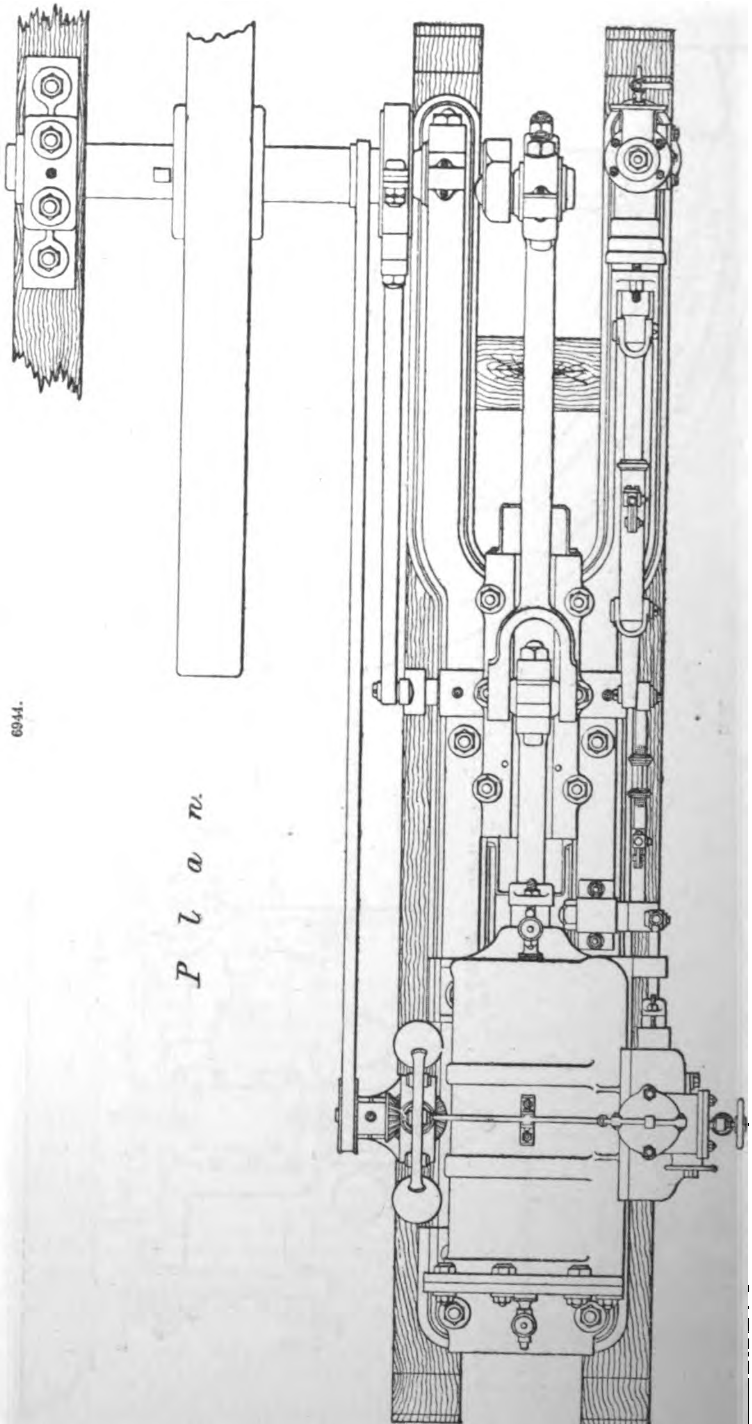


6943.

Side Elevation

it may very well be that the engine would work better and do more work with this large drop than without it."

There are three types of stationary engines, distinguished in one case by the medium of transmission, and in the other cases by the position of the cylinders. The first and oldest is that

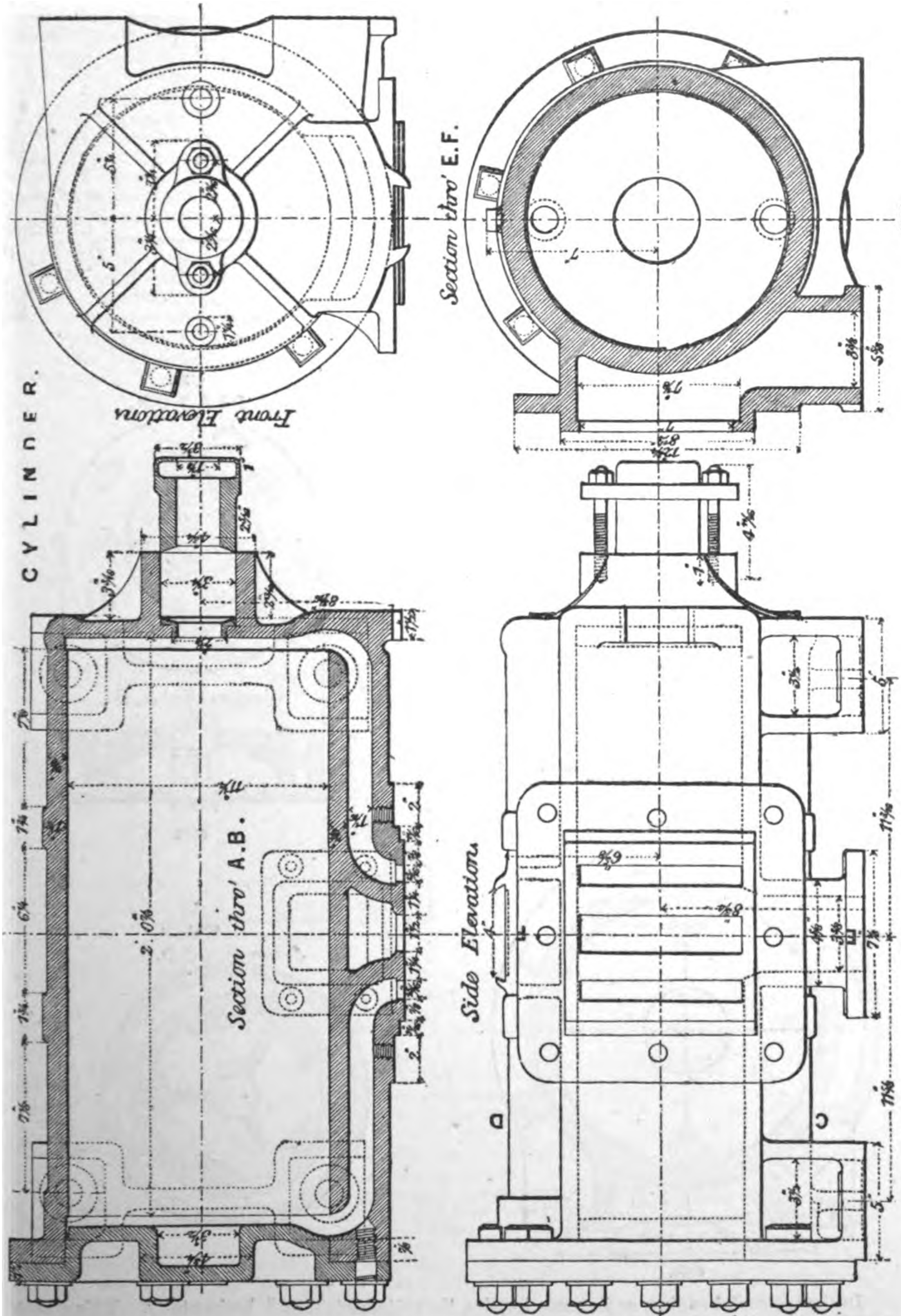


6944.

Plan.

known as the beam-engine, so called because the motion of the piston-rod is communicated to a heavy oscillating piece called the beam, which transmits the motion to the machinery to be driven.

This type, except for pumping purposes, for which the motion of the beam is very suitable, is gradually going out of favour. It is difficult and costly to construct; it demands more care and precaution in certain parts of its construction, and more time and attention for its erection. It requires for a given power more solid foundations than the other types, and it is not favourable to economy



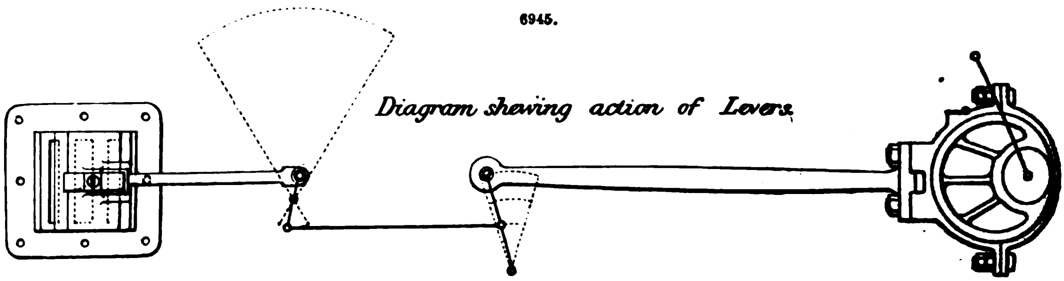
6947. 6949. 6951. 6946.

of fuel. Moreover, it allows but little latitude in its application, and is utterly incompatible with high piston velocities. On the other hand, its motion is extremely regular and majestic, and when of great power, it presents an imposing appearance.

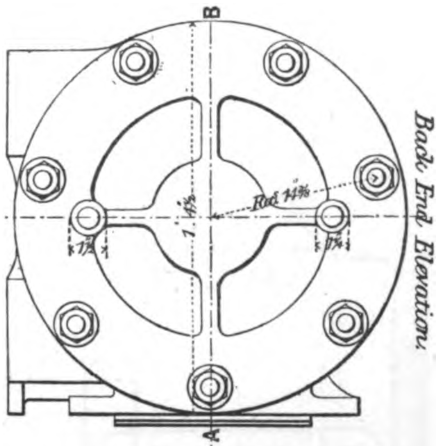
The chief condition to be fulfilled in designing an engine on this system, is to give the beam

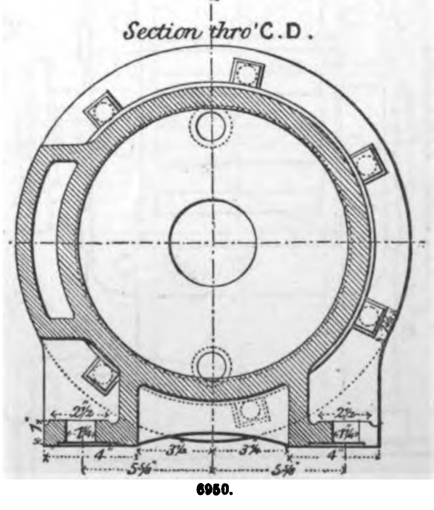
such length that the angle which it describes may be as small as possible, so as to diminish the influence of the versed sine of the arcs in decomposing the motion. Theoretically this length should be infinite; in practice it is usually made equal to three times the stroke of the piston. In some American engines the beam is made shorter than this, but in our opinion a still greater proportion than 3 to 1 is desirable. With this proportion, the angle described by the beam is about 38° 20′, and the versed sine of the arcs is 0·075 of the stroke.

6945.



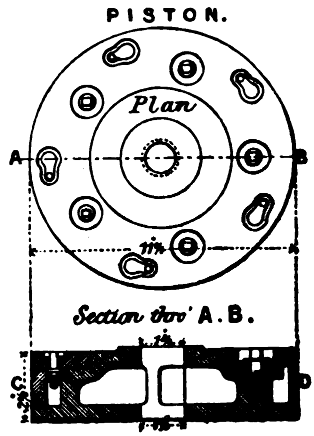
6948.





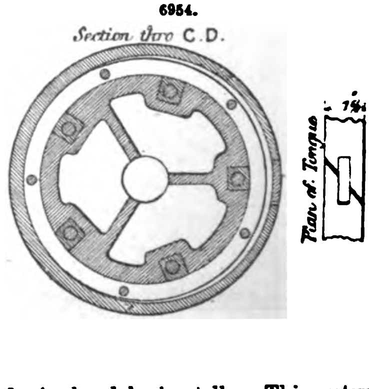
6950.

6952.



6953.

6954.



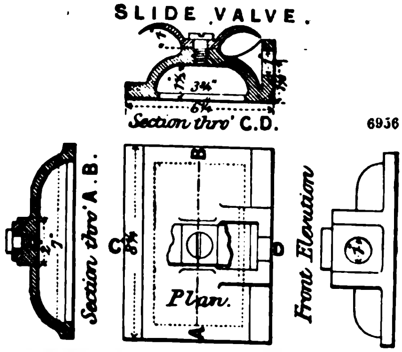
In the horizontal engine, as its name implies, the cylinder is placed horizontally. This system may be said to have produced a revolution in the use of steam-engines. Its numerous advantages have rendered its adoption almost general, in spite of the strong prejudices arrayed against it on its first introduction. Engines constructed on this system are remarkable for their simplicity, their solidity, and their economy. Occupying but little space, they may be erected in positions totally unsuitable for a beam-engine, and may be easily examined or repaired when out of order. As the

breadth of their base is great relatively to their height, very high speeds may be attained without fear of the vibration which would be caused in other systems. The little foundation required is also a source of economy that in some cases may be of considerable importance. This class of engine is rapidly taking the place of the beam-engines, and it may be regarded as the type of the present day, and the most advanced stage of steam-engine construction.

The third type of engine is the vertical, in which the cylinder and the organs of motion and transmission occupy the same position as in the beam-engine. In this type, however, the connecting rod is directly connected with the crank of the driving shaft, which may therefore be either above or beneath the cylinder. Its parts being compactly disposed, it occupies only a small space, and it may be readily examined and repaired. In certain cases where the space is restricted it may be advantageously employed; but where no such restrictions exist, it can never compete in efficiency with the horizontal type.

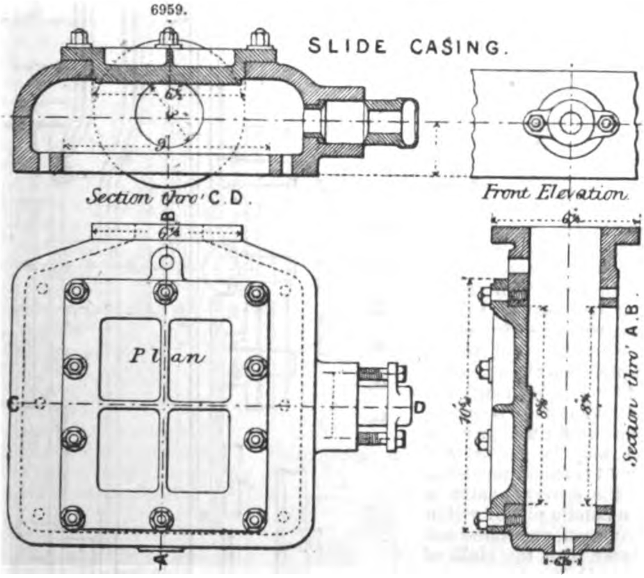
It would be superfluous to give the details of these several types of engines in this place, as they have already been described in former articles. We shall therefore content ourselves with giving an example of the beam and the horizontal types, as illustrations of the most recent design and construction in those systems.

6955.



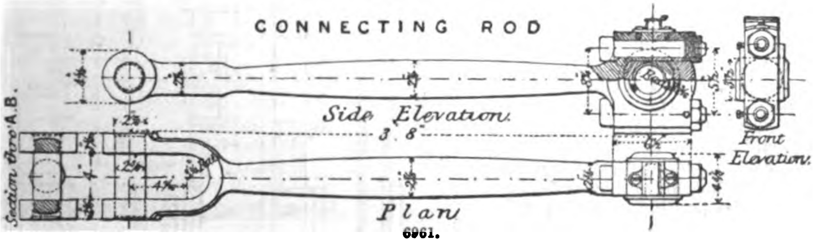
6956.

6959.



6957. 6958.

6960.



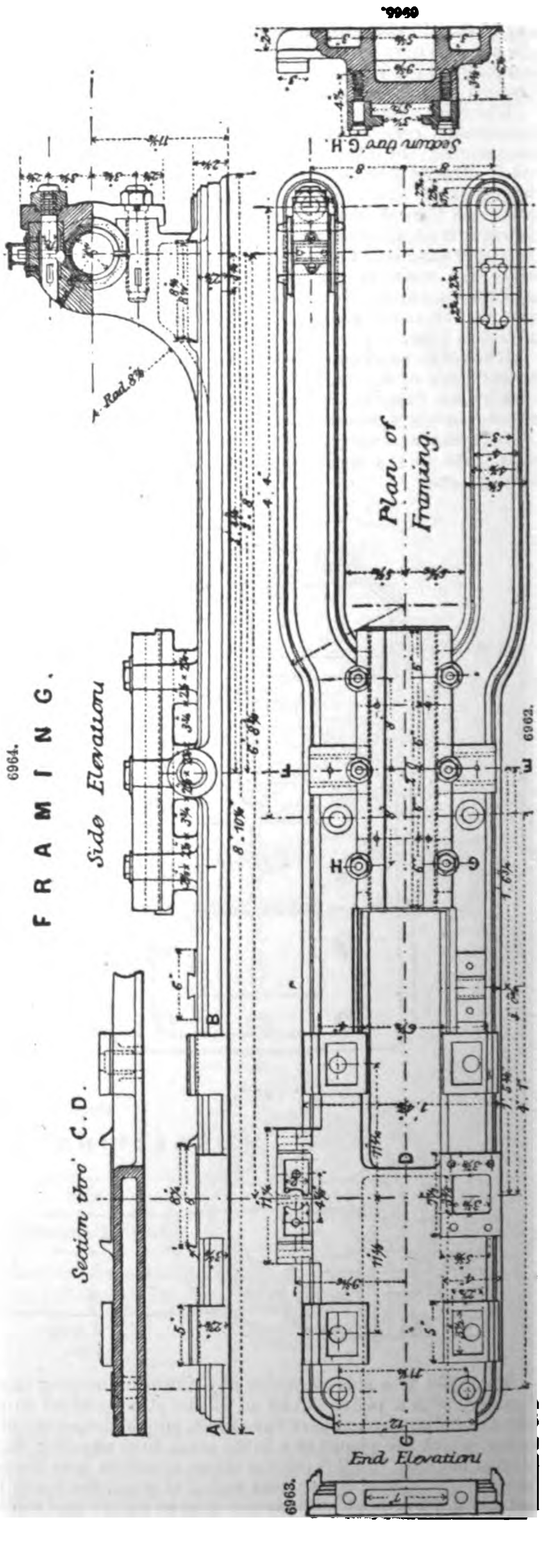
6961.

Fig. 6938 is a side elevation of a Cornish pumping engine. The cylinder A is 70 in. internal diameter, with a piston-stroke of 10 ft.; it is enclosed in a cast-iron steam-jacket communicating with the boilers by means of the pipe *a*, which also serves to return the water of condensation to the boilers, which are placed at a lower level, thus avoiding the waste of heat, which is often met with in other engines, by allowing the steam to escape from the jacket at nearly the boiling point. This jacket is surrounded by another casing of wood, the space between the two being filled with some bad conductor of heat, such as saw-dust or ashes; and the whole is enclosed by a casing of brick-work, or by an air-tight cavity formed by building a thickness of brickwork at a few inches distance,

which is plastered on the outside and covered with wood panelling. The cylinder cover and bottom are also protected from the cooling influence of the air; the former being fitted with a false lid or cap *c*, enclosing a thick layer of saw-dust or other bad conducting substance; and the space *d* under the bottom kept constantly filled with steam by a branch from the pipe *a*.

B is the main beam, cast in two plates and bolted together, with distance blocks between to keep them parallel with each other. To the upper part of the beam is fixed transversely, by means of brackets, a strong bar of iron, *g*, called the catch-piece, which, when the piston arrives at the bottom of its stroke, touches the blocks *h*, fixed on the spring-beams; the descent of the piston being thus arrested, no damage can be done to the cylinder by the engine making too long a stroke in-doors. C is the plug-rod for working the valves and cataract. D, the top nozzle, shown in section in Fig. 6939, contains three valves. First; V_1, the governor or regulating valve, for regulating the admission of steam into the chamber *k k* of the nozzle, whence it afterwards passes through the steam-valve V_2 into the cylinder. The opening of the governor-valve is constant during the working of the engine, that is, it is not moved by the engine, but only occasionally by hand, for the purpose of regulation. In proportion as the governor-valve is more or less raised, the steam is less or more wiredrawn, or reduced in pressure, as it passes from the steam-pipe into the cylinder. By this means therefore, although the pressure in the boilers may occasionally vary, the mean effective pressure in the cylinder may be maintained constant with great ease and precision. The motion of the governor-valve is commanded by a handle placed within reach of the engineman, and connected by a rod and lever with the stalk of the valve. Second; V_2, the steam-valve, for admitting the steam into the cylinder. When this valve is raised, the governor-valve being supposed open also, the steam finds a passage through it, from the nozzle-chamber *k k* into the space *l*, and thence by the steam-port *m* into the upper part of the cylinder. The chamber *k k*, Fig. 6939, would appear to be divided by the cover a_3, belonging to the equilibrium-valve; but this appearance only arises from the position in which the line of section is taken, the steam being free to pass round, in the direction of the arrows, from the governor-valve to the steam-valve. Third; V_3, situated in the middle of the nozzle, is the equilibrium-valve, for opening the communication between the spaces above and below the piston. When therefore this valve is opened, the steam above the piston will, by its

FRAMING.



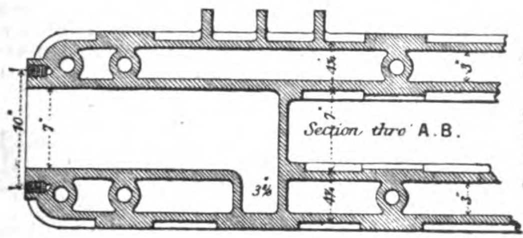
excess of elasticity, find its way along the equilibrium-pipe E, and by the lower port n, into the lower part of the cylinder, until the equilibrium is restored between the pressures above and beneath the piston; which is then at liberty to be drawn upwards by the preponderating weight of the rods hung at the outer end of the beam.

It will be observed that the three covers, a_1, a_2, a_3, which are bolted to the nozzle over the governor, steam, and equilibrium valves respectively, are of sufficient size to allow the valves to be lifted from their seats and taken out of the nozzle when the covers are removed, thus giving the opportunity for convenient examination or repair. The top nozzle is, like the cylinder-jacket, enveloped in an external casing of thin iron, leaving a space all round, which is filled with ashes or saw-dust to prevent loss of heat.

F is the bottom nozzle, a section of which is shown in Fig. 6940; it contains the exhaust-valve V_4, for opening or closing the communication between the lower part of the cylinder and the condenser. The nozzle-chamber above the valve communicates with the cylinder by the lower port n, while to the bottom of the nozzle, under the valve, is attached the eduction-pipe H; so that when this valve is lifted, the steam in the lower part of the cylinder is exhausted into the condenser.

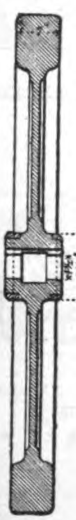
G is the cataract, shown in section in Figs. 6941, 6942. The use of this ingenious apparatus is to regulate the period of opening the steam and exhaust valves, and thus to determine the interval between the successive strokes of the engine, that its rapidity of action may correspond with the quantity of water to be drawn from the mine. a' is a barrel in which works the plunger b', and which is simply a small plunger forcing pump. The inlet is by a valve c', opening freely upwards, but the outlet is contracted at pleasure by a movable plug d'. The pump is placed in a cistern of water G, and the plunger is attached by the joint to the arm e' of the lever $e'f'$. When the plug-rod C has descended nearly to the bottom of its stroke, a tappet upon the lower part of it strikes the end f' of the lever and thus raises the plunger b', the water at the same time entering freely under the plunger through the valve c'. When the stroke is finished and the plug-rod begins to ascend, the tappet quits the lever, and the weight h' which is fixed upon

6967.



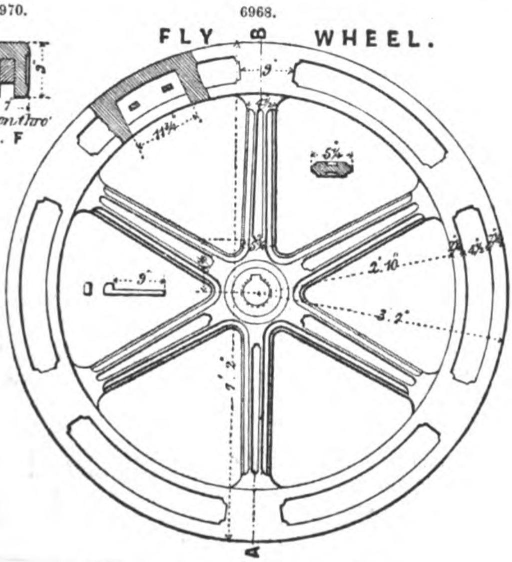
6966.

6969.



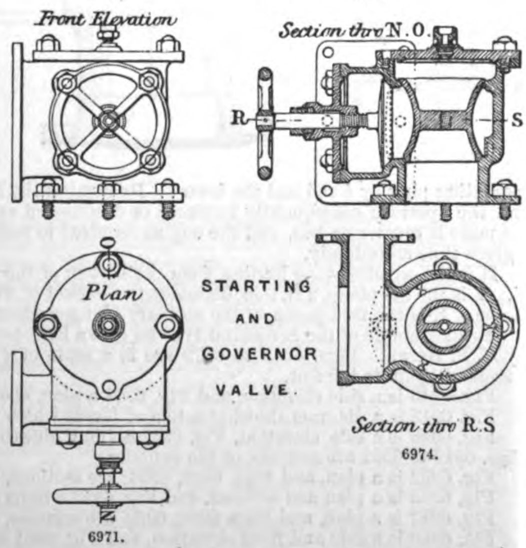
6970.

6968.



6972.

6973.

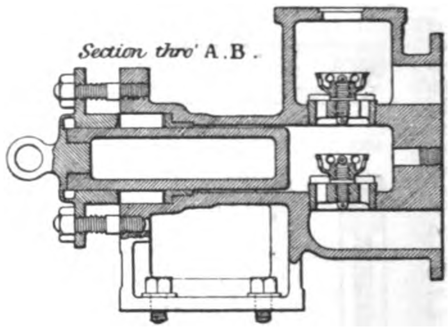


6974.

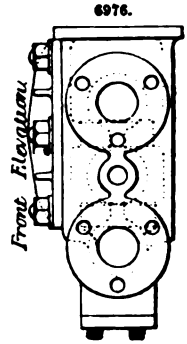
6971.

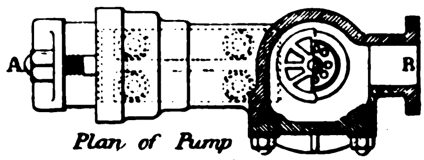
the arm e', and which has been raised by the preceding motion, becomes in its turn the motive power, tending to expel the water from the pump by forcing the plunger down. But the inlet-valve c' having closed, the only exit for the water is by the aperture left round the regulating plug d'. It is plain, therefore, that by augmenting or diminishing the size of this aperture, the exit of the water, and thereby the descent of the plunger, may be accelerated or retarded at pleasure. To the end f' of the cataract-lever is attached a rod m, which ascends vertically, opening first the exhaust, and a short time after the steam valve, thereby causing the commencement of the next stroke of the engine. It should be remarked that the rod m acts upon a catch that releases the weights w; these, by their fall, open the valves and occasion a suddenness of action which is considered a great advantage, particularly as regards the admission of the steam into the cylinder by the steam-valve. It is evident, then, that the interval between the time the tappet leaves the cataract-lever and the commencement of the next stroke, which in fact determines the interval between two consecutive strokes or the number made in a given time, depends upon the time occupied by the descent of the cataract-plunger, and therefore, ultimately, upon the degree of opening given to the regulating plug d'. This can be adjusted to a great nicety by means of a micrometer screw and handle connected with the

6977.



6976.

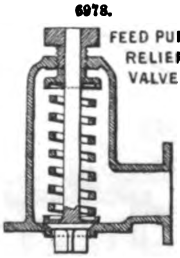




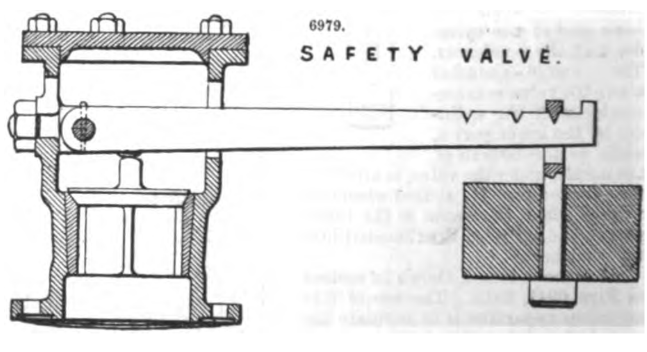
6975.

FEED PUMP.

6978.



6979.



regulating plug by a rod and the lever l'. By turning the handle the plug can be raised or lowered, and the aperture consequently increased or diminished as the quantity of water to be raised from the mine is greater or less, and the engine required to make a greater or less number of strokes in a given time accordingly.

H is the eduction-pipe leading from the bottom of the exhaust-valve nozzle F to the condenser K. L is the air-pump, 2 ft. 9 in. diameter, the bucket of which has a stroke of 5 ft., half that of the piston. N is the feed-pump, of the ordinary plunger description.

As an example of the horizontal type we give a high-pressure engine of 12 horse-power designed by N. P. Burgh. Figs. 6943 to 6979 are to a scale of $\frac{3}{4}$ in. to the foot; the remainder being to a scale of $1\frac{1}{2}$ in. to the foot.

Fig. 6943 is a side elevation, and Fig. 6944 a plan, showing general arrangement.

Fig. 6945 is a diagram showing action of levers which command the slide-valve.

Fig. 6946 is a side elevation, Fig. 6947 a front elevation, Fig. 6948 a back end elevation, and Figs. 6949 to 6951 are sections, of the cylinder.

Fig. 6952 is a plan, and Figs. 6953, 6954, are sections, of the piston.

Fig, 6955 is a plan and sections, and Fig. 6956 a front elevation, of the slide-valve.

Fig. 6957 is a plan, and Figs. 6958, 6959, are sections, of the slide-casing.

Fig. 6960 is a side and front elevation, and Fig. 6961 a plan, of the connecting rod.

Figs. 6962, 6963, are a plan and end elevation, Fig. 6964 a side elevation, and Figs. 6965 to 6967 are sections, of framing.

Fig. 6968 is an elevation, and Figs. 6969, 6970, are sections, of fly-wheel.

Fig. 6971 is a plan, Fig. 6972 a front elevation, and Figs. 6973, 6974, are sections, of the starting and governor valve.

Fig. 6975 is a plan, Fig. 6976 a front elevation, and Fig. 6977 a section, of feed-pump.

Fig. 6978 is a section of feed-pump relief-valve, and Fig. 6979 a section through safety-valve.

See Boiler. Details of Engines. Engines, *Varieties of.*

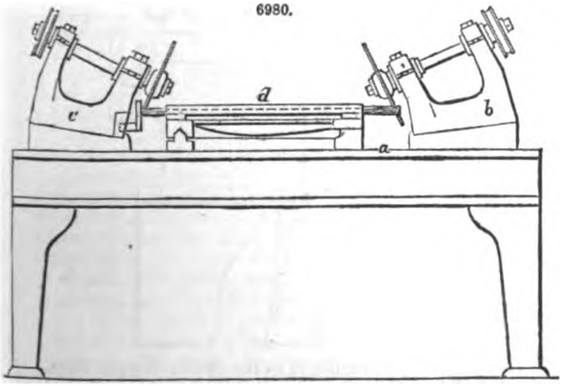
STAVE-MAKING AND CASK MACHINERY. Fr., *Machines à fabriquer les douves et les barils;* Ger., *Dauben und Fass-Maschinerie;* Ital., *Macchina da botti;* Span., *Maquinaria para hacer duelas y barriles.*

George Hadfield's Machines for making Casks.—Much of the machinery used in the manufacture of casks has in itself no pretensions to novelty; but no good idea could be given of the system without carrying the reader through the various processes. Let it be supposed that casks of 36 gallons are required to be made for containing beer. The timber employed is that known in the market as Dantzig pipe staves, which measure 5 ft. 10 in. to 6 ft. long, and in cross-section present a square figure of about the dimensions of the breadth of the stave to be cut. The square logs are first cut into lengths, equal to the length of stave required, and the short ends put aside for making the cask-heads. In order to cut up the logs expeditiously, a fixed trough or angular guide is provided to receive the log, whose end is brought up against a fixed stop near the end of the guide. A transverse slit through the guide allows a circular saw to pass through it and sever the wood. The saw is carried at the extremity of a balance-frame, which is depressed by hand, to bring the saw on to its work. It is driven by a band from a pulley on the cross-shaft, which forms the fulcrum for the frame.

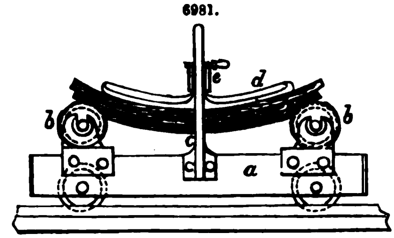
The blocks, thus prepared, are next split up to the proper thickness for staves, by the aid of a saw-bench; the block being pressed by hand against a rotary saw, which projects up through the table of the machine, and guided by a fixed vertical gauge-plate, over the face of which the block is slidden by the workman. In this way each block is divided longitudinally into six staves. In like manner the short pieces before mentioned are slit up, to form the heads of the cask.

The next operation is to gauge the length and bevel the ends of the staves. This is done by a machine, shown in front elevation at Fig. 6980. It consists of a bed *a*, carrying two headstocks *b*, *c*, the latter of which is adjustable. On the headstocks are mounted a pair of inclined rotary saws, for gauging and bevelling the staves. Between the saws is a sliding carriage *d*, on which the staves are severally laid, and the workman, holding the stave firmly, thrusts the carriage forward on its slides, and passes the ends of the stave under the action of the rotating saws. He then draws back the carriage, and repeats the operation. This is the first shaping operation; and at this stage the stave is simply a flat piece of wood of uniform thickness, but with bevelled ends, and its side edges are square and parallel to each other. It must, however, have imparted to its outer face a convexity, both in the direction of its length and its width, besides being tapered and bevelled.

6980.



6981.

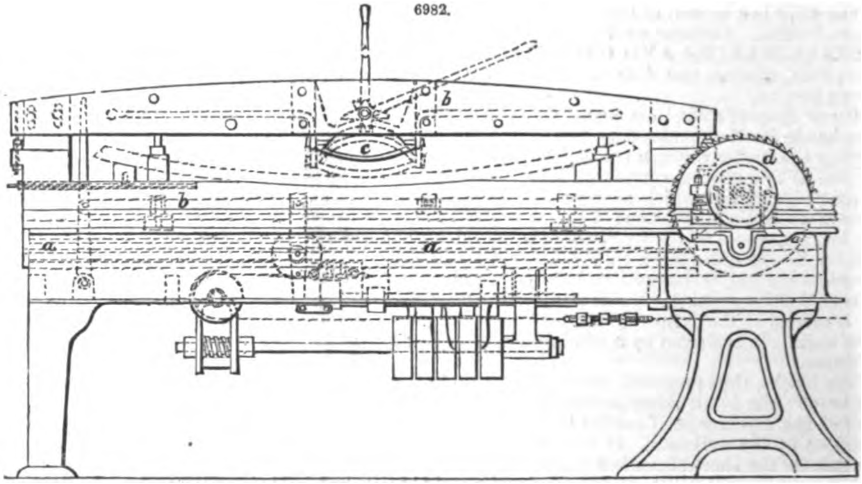


To produce the requisite convexity, a steaming and bending process is adopted. The staves are thrown into a steam-chest, and subjected to the moistening and heating effect of the steam for about five minutes, to soften the wood. They are then packed upon carriages similar to that shown in side view at Fig. 6981. A series of these carriages is provided, to run upon a double line of rails laid under a shed, containing the steam-chest. The carriage, it will be seen, is a kind of truck *a*, on which two transverse rollers *b*, *b*, are mounted, for supporting five piles of staves abreast of each other. The periphery of these rollers is concaved, to give a transverse convexity to the staves, when pressed down upon them, and midway between the rollers *b* is a pair of standards *c*. The carriage, when laden with the piles of hot staves, is moved forward under a screw press standing over the railway. A transverse bar, provided on its under side with curved pressing pieces *d*, is then forced down by the press into contact with the staves, until they take the curved form, Fig. 6981. Pins or holdfasts *e*, passed through the standards *c*, then retain the pressing bar in its place, and the carriage is released from the press to allow of a second carriage-load of staves being similarly treated. The carriage, when released from the press, is turned on to a second line of rails, and there left for the staves to cool, and thus receive a permanent set.

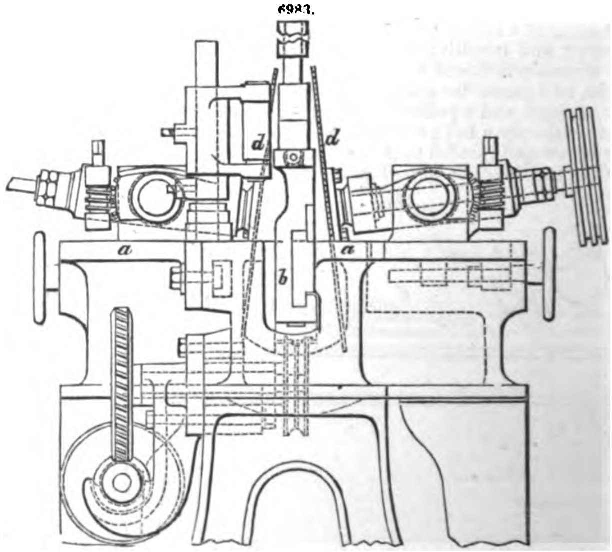
The next operation is the jointing of the staves; that is, the tapering of the opposite ends, and the bevelling of the edges. By hand, this operation is very irregularly performed, a hand-plane being used, guided only by the practised eye of the workman. The surface of the joint is, moreover, smooth, which increases the tendency of the staves to start when the cask is subjected to rough

usage. In the jointing machine, shown in side elevation at Fig. 6982, and in partial end elevation on an enlarged scale, Fig. 6983, the staves are jointed, so as to be practically identical. No

6982.



6983.



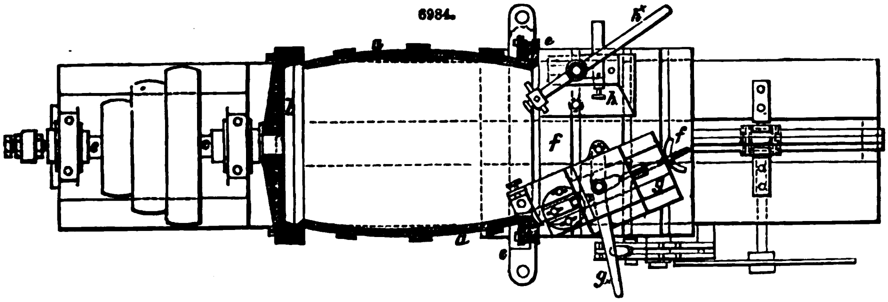
fitting therefore is required when setting them up to form casks. This machine consists of a long bed *a*, over which traverses, supported in suitable guides, a clamping *b*. This carriage receives motion from an endless chain, which moves alternately in opposite directions. The carriage is fitted to receive a curved stave and hold it down firmly by means of a clamp *c*, while the stave is presented to, and passed down under the action of, a pair of inclined saws *d*, *d*, which are adjustable both to and from each other, and in their inclination, to suit different sizes of staves. When the carriage is at either end of its traverse, the attendant takes a curved stave and clamps it in the carriage. The return motion will bring the stave under the action of the inclined saws, which will simultaneously joint the opposite sides of the stave, thereby reducing it to the required taper form. The attendant then raises the clamp *c*, puts in and clamps a fresh stave, and the reverse motion of the carriage brings the stave, in like manner, under the action of the saws. No time is therefore lost in the working of the machine.

In the manufacture of ale barrels, more especially those intended to receive pale and delicately-flavoured ales, it is important to get out the tannin from the wood. This is usually done by the process of charring, but the inner surface of the barrel is thereby injured. To avoid this, a steaming process is adopted. The staves to form the cask are put together and bound by temporary truss hoops. The cask is then set upon an iron plate and over a steam-pipe which projects through the plate, and the top of the cask is covered by a loose head. Superheated steam is then let into the cask, and in about five minutes the dissolved tannin will trickle down out of the pores of the wood.

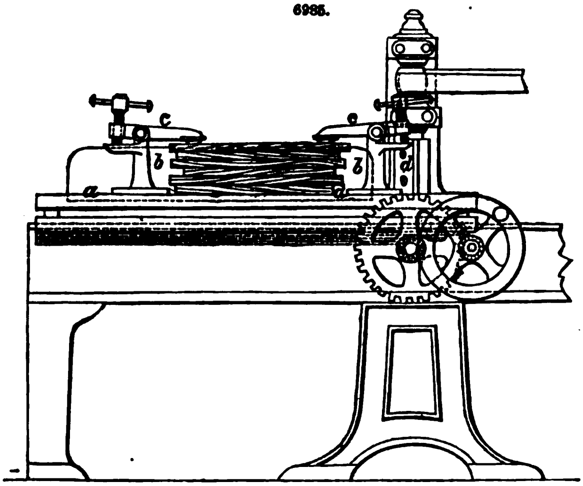
The operation of finishing the ends of the cask, termed chining, which fits it to receive the heads, is effected in a peculiar adaptation of lathe, which is shown in plan, Fig. 6984; the barrel and its supports being in section. One end of the barrel *a* is inserted in a chuck *b*, carried by the mandrel *c*, and the other end is supported by a cone-faced annular chuck *d*, mounted in a bearing *e*, carried by a sliding table *f*, which is capable of adjustment lengthwise of the lathe-bed. This table *f* also carries two slide-rests *g*, *h*, in which are fitted the cutters for chining the barrel. The cutters of the slide-rest *g* finish the bevelled edge, and also hollow the inner face of the barrel; and the cutter of the slide-rest *h* turns the groove for receiving the barrel-head. Rotary motion is given to the barrel, and the cutters are brought into action by the attendant moving the cutters by the

hand-levers g^* and h^*. When one end is finished, the barrel is released from the chucks, and its other end is, in like manner, submitted to the cutting tools.

6984.



6985.



Having thus far followed the shaping of the staves, and the conversion of the same into cask bodies, it will be necessary to direct our attention to the formation of cask-heads. This is comparatively a simple operation, but it has, nevertheless, developed some ingenious mechanical devices. The wood to form the heads having been split up as already described, is submitted to a jointing machine, Fig. 6985, for squaring the edges. The wood is piled up on a travelling table a, against a gauge-plate b, and held firmly by clamps c, c. The traverse motion of this table over the bed of the machine carries the wood past a rapidly rotating cutter d, which planes the edges presented to its action. The clamps are then slackened, and the pieces requiring both edges to be jointed are again submitted to the action of the cutter.

The dowelling together of the pieces is the next operation. For this purpose their contact edges are in turn pressed into contact with rotating drills, which rapidly drill the dowel-holes. The dowel-pins are made by a simple machine, which, by a rotary saw, cuts up strips of wood in width corresponding to the length of pins required, and then, by a rotary hollow cutter, rounds the ends of the pins. These pins are driven into the drilled holes of one piece, and a corresponding drilled piece is forced into contact therewith; and in like manner some four or five pieces, which are to form a head, are hammered together, and held fast by the dowel-pins. The next operation is to cut these dowelled pieces into a circular disc, for which purpose a modified form of band-saw is used.

6986.

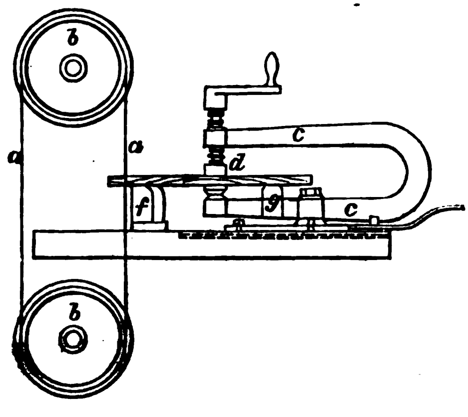
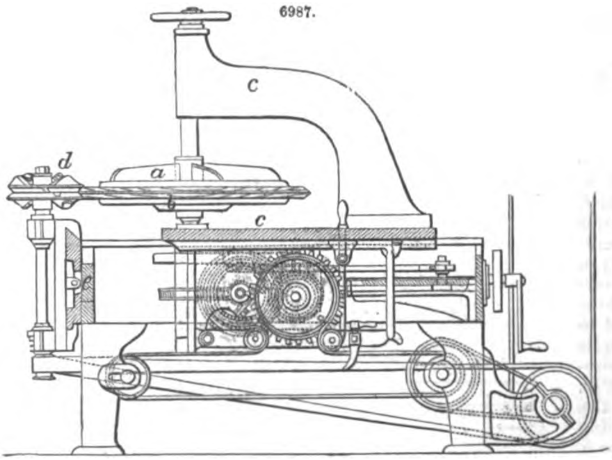


Fig. 6986 shows in elevation so much of a band-saw adapted for cutting out the heads of casks, as will explain its action; the object being to cut the heads with rapidity, and of any desired size. a is the saw-blade, running over tension-pulleys b, b. On a plate capable of sliding in guides on the table of the machine, is mounted a horse-shoe swing frame c, for receiving the wood to be cut. This frame is capable of adjustment to and from the saw, to suit different diameters of cask-head. The frame c is provided with two swivel clamping jaws, d and e, the upper one of which is capable of being raised and lowered by a vertical screw and winch-handle, for the purpose of clamping the dowelled wood that is to be placed between them. Rests f and g are used for steadying the wood.

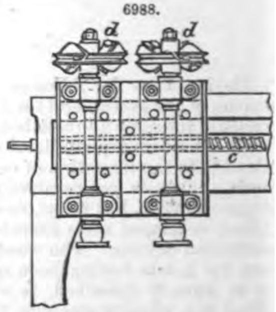
To bring the work into contact with the saw, it is only necessary to swing the frame *c* on its fulcrum, and the saw being set in motion, it will quickly enter the wood. The attendant then gives the wood a slow axial motion under the saw, which shapes it into a circular disc. This being done, he slackens the clamps, and releases the disc; then puts in another head, and repeats the operation.

In order to complete the head, its periphery has to be bevelled, to fit the groove in the cask; and to ensure a permanent tight junction with the cask, it has been found necessary to turn the head oval, that is, with a slightly superior diameter, across the grain of the wood; this is to allow for shrinkage. For this purpose, the machine shown in side elevation, Fig. 6987, and in partial end view, Fig. 6988, is employed. It is somewhat complex in its construction, but

6987.



6988.



the following description will give a fair notion of its action. The disc to be turned is placed between swivel-clamps, *a*, *b*, which are carried by a sliding table and bracket-arm, *c*. The disc is held by the table and bracket in the line of cut of a pair of rapidly rotated cutters, *d*, *d*, which are mounted on a traversing vertical frame, that slides across one end of the machine. These cutters are driven in opposite directions, and are intended to act alternately on the head, and thereby cut the wood in the direction of the grain, without the rotation of the head being required to be reversed. A slow intermittent axial motion is given to the head, by gearing operating the spindle of the lower clamp *b*; and at the same time a slight traverse is given to the table *c*, with its bracket-arm, in order to ensure the oval or irregular turning required. The cutters are suitably formed to cut a double bevel, and they are moved into and out of work by the attendant, who, watching the axial movement of the head, slides them to and fro as required, by turning a traversing screw *e*. The head being finished, the upper clamp *a* is raised by the hand-wheel, and the head replaced by another disc; care being taken to place it in the machine so as to ensure the larger diameter being crosswise of the grain.

6989.

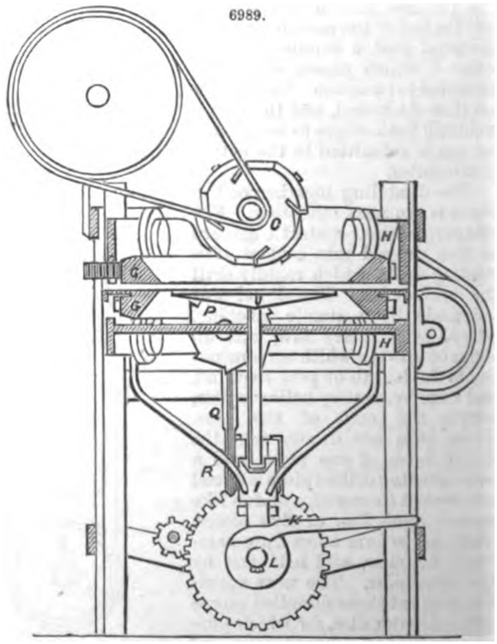


Fig. 6989 serves to illustrate the action of Alfred Beuster's barrel-heading machine. The object of this machine is to plane the upper surface of a barrel-head to the desired oval shape, make the upper and lower chamfer, and also to revolve, clamp, and loosen the work automatically, the attention of the operator being only required to arrange the pieces for a head on a table in front of the machine and push them forward. In doing this, the finished head is pushed out on the opposite side of the machine and deposited on a table placed conveniently to receive it. Referring to Fig. 6989, C is a revolving planer; G, G′, revolving toothed rings; and H, H′, rising and falling frames, arranged to act in combination with the planer C; U is a turn-table; P, a revolving cutter; I, standard; K, a hinged board; R, a lever; Q, a sash, the alternating motion of all these parts being given by the cam L.

In banding or trussing casks, it is well known that the metal hoops require to be slightly coned, to allow of their fitting tightly the tapering periphery of the cask. This is effected by a modification of the machine of Horsfall and James. The hoop iron, having been cut to lengths, and punched to receive the rivets for coupling the ends, is passed between a pair of nipping rolls, one being set slightly out of the horizontal. A tighter nip is therefore given to one edge than the other, and the metal is thereby slightly spread at one edge. A third roll, set higher than the nip of the pair of rolls, turns the hoop iron upwards, and causes it to curl into the form of a hoop, which hoop is then riveted by hand, as usual.

The casks may be trussed by hand, but preferably they are trussed by a modification of the machine of Robertson. This machine consists of two conical metal cases, which fit one on to the other; one being fixed, and the other movable, by the action of a press. The cask may be built up or inserted in one of these conical cases, which are each divided down their middle, and the parts coupled by tightening screws. They are also grooved, to receive the metal hoops. When, therefore, pressure is applied to bring the two conical cases together, the cask is forced into the hoops placed in the grooves or recesses. By slackening the coupling screws and separating the conical cases, the cask, now mechanically trussed, is readily removed from the machine.

With the assistance of three attendants, the steaming and bending of the staves, to fit them for the jointing machine, may be effected at the rate of forty staves in five minutes. The jointing of these staves, with the aid of one attendant, is completed at the rate of three a minute. To chine a cask—that is, to turn and groove the ends—with a man attending, requires three minutes. Rounding the cask-heads by the band-saw is effected at the rate of sixty an hour. And the oval turning and bevelling of the heads is completed at the rate of twelve pairs an hour.

See Wood-working Machinery.

STEAM-CRANE. Fr., *Grue à vapeur;* Ger., *Dampfkrahn;* Ital., *Gru a vapore;* Span., *Grua de vapor.*

See Lifts, Hoists, and Elevators.

STEAM-ENGINE. Fr., *Machine à vapeur;* Ger., *Dampfmaschine;* Ital., *Macchina a vapore;* Span., *Máquina de vapor.*

See Boiler. Engines, *Varieties of.* Stationary Engine.

STEEL. Fr., *Acier;* Ger., *Stahl;* Ital., *Acciaio;* Span., *Acero.*

The term steel is vaguely applied to certain combinations of the metal iron with carbon; thus considering wrought iron to contain little or no carbon, cast iron as much as 5 to 10 per cent. of carbon, steel has been regarded as occupying an intermediate position; but as there is no boundary-line existing in reality, and as the percentage of carbon can be decreased by the slightest shades, gradually forming a continuous series between cast iron on the one side and wrought iron on the other, there is no possibility of taking out any particular part of this continuous gradation and distinguishing it by the name of steel. Other substances, such as tungsten, wolfram, also enter into the composition of steel, and considerably modify its properties and uses. It would be a good method, therefore, to call every combination of iron with another chemical element a steel; and to distinguish between the varieties of steel, both with regard to qualitative and quantitative differences of composition.

The colour of steel is a bright greyish-white; its texture is uniformly granular, the better the quality the smaller the grain. Sound soft, that is, unhardened, steel never exhibits the coarse texture characteristic of crude cast iron, nor the fibrous texture of bar iron. Hardened steel shows a fracture very similar to that of the finest silver, so close that the granular texture can hardly be detected by the naked eye. When red-hot, steel is nearly as malleable as bar iron, and may be welded, but very careful management is required to prevent its becoming decarbonized By immersing a piece of steel in dilute hydrochloric or nitric acid the texture of the metal becomes apparent, and this test may be applied to determine the quality. The specific gravity of steel varies from 7·62 to 7·81, and decreases in hardening. The toughness, tenacity, and hardness of steel increase with the quantity of carbon it contains, but good steel never contains graphite. The high degree of elasticity exhibited by good steel decreases with the hardness.

After what has been said on alloys generally, and on those of iron in particular, it is not difficult to understand the relation in which carbon stands to iron; and there is no doubt as to the necessity that it should be present in iron in order to constitute steel. We find, so far as carbon is concerned, that iron with less than ·65 per cent. of carbon is wrought iron; from that to 2·3 per cent. of carbon, forms steel; and when the quantity of carbon is larger, the metal is considered cast iron There are other substances which impart hardness to iron, and perform in that respect a similar office to carbon.

The different methods employed for producing steel may be classified as follows;—

1. From the ore direct, by reduction and carbonization. Ore steel.
2. From pig iron by decarbonization. Pig-iron steel. By means of gaseous oxidizing agents, as air in the Bessemer process. By means of solid oxidizing agents, as are saltpetre, and so on, as in the puddling process and Heaton's process.
3. From wrought iron by carburation. Wrought-iron steel. By fusion with pig iron, as in the Siemens-Martin process. By fusion with carbonaceous matter, as in Mushet's, or the Indian processes. By heating in charcoal below fusion, as in the cementation process. By heating in an atmosphere of carburetted hydrogen without fusion, as in Macintosh's process.

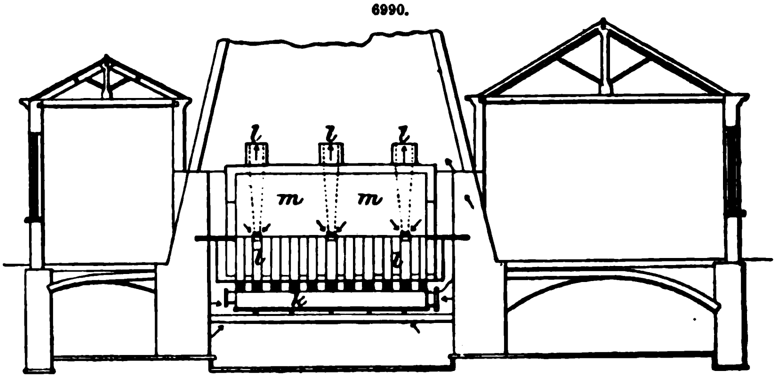
A comparison of specimens of various kinds of steel shows that the quality of the metal depends chiefly upon the nature of the raw materials used, and accordingly it is only where the very best ores and purest coals are employed that we find the finer grades of steel produced.

We shall not here describe all the numerous methods in use for the manufacture of steel, but only those most extensively practised.

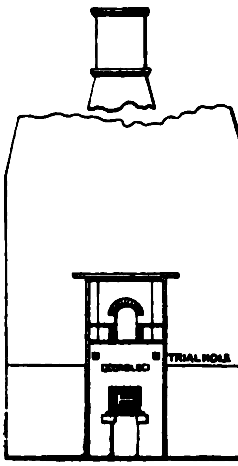
Cementation Steel.—The converting furnace used in the manufacture of cementation steel, consists of two rectangular chests, called pots, *i, i*, Figs. 6990 to 6993, made of silicious freestone or

fire-brick; capable of bearing a great degree of heat unchanged. If of freestone, the stone is cut at the quarry into rectangular pieces, all 6 in. thick, and so arranged as to form, when put together,

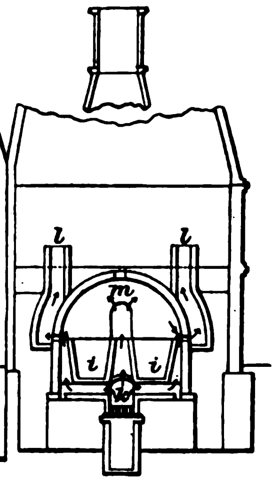
6990.



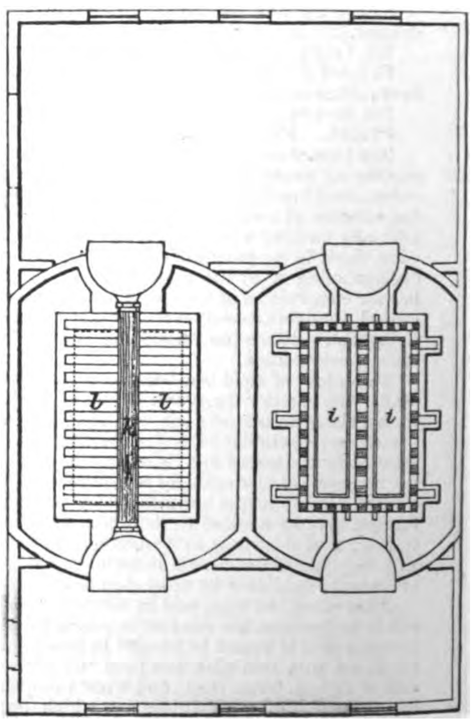
6991.



6992.



6993.



two chests from 12 to 14 ft. long, and about 3 ft. 6 in. wide and deep, supported, even where the ground is tolerably favourable, upon about 4 ft. of solid masonry; for it is of the greatest consequence that there should be no sinking or giving way of the foundation, so as to crack the chests and admit air, which would spoil the conversion. The masonry should finish with a course of fire-brick; and upon that again is laid cross-walls of fire-brick, 10 in. thick and the same distance apart, upon which the chests will immediately rest, while the brick divisions form flues underneath them. The chests are placed 18 in. from, and parallel to, each other; and the space between them is divided into flues *l*, *l*, corresponding with those which pass underneath, up the opposite side, and at the ends of the chests, into the fire-brick wall which covers them all.

This vault *m* has an arched opening at each end, large enough for a man to creep into when it is required to lay in iron or take out steel; at other times they are bricked up temporarily, and plastered with clay or wheelswarf, a mixture of grit and steel dust obtained from grindstones employed to grind steel articles. There are also two small temporary openings, one over each chest, through which bars can be put; and in these a piece of sheet iron is laid when so used, with the edges turned up, to pass the bars more easily and prevent injury to the brickwork.

Out of the vault rise three small chimneys on each side opening into the large cupola, which carries the smoke to a considerable elevation, and prevents the wind from having much effect upon the draught of the furnace fire. The fire-grate *k* is under the middle row of flues, and the whole length of the chests. It has a strong metal door at each end, which is kept close shut, except when a fresh charge of coal is being put in. The fire-brick work and also the chests are built with ground-clay and water, mixed to a proper consistence, instead of lime mortar.

The bars of iron submitted to this process are principally from 2 to 3 in. broad and ⅝ to ¾ in.

thick, except where they are required for railway springs, and then they are made from 3½ to 4 in. in breadth. A layer of charcoal powder is spread over the bottom, then a layer of bars, and so on alternately. The edges of the bars are laid so as to touch each other, or nearly so, without any particular allowance for expansion in that direction; the inequalities in the bars being sufficient for that purpose. A layer of bars should be covered about ½ in. thick with charcoal, finishing with a thicker layer than usual over the top. After both chests are filled they are covered over with from 4 to 5 in. in thickness of wheelswarf. This grit contains a portion of iron and steel, and their oxides, in minute divisions, intimately mixed with the grit, which seems to possess the valuable property, for this purpose, of undergoing a partial fusion when hot, and forming a kind of cindery slag, which perfectly protects the steel underneath from the action of the air.

Each furnace has a square opening of about 5 in. in the centre of the end of one of the chests, which is continued through the walls to the outside of the furnace, into which two or three bars, called tap-bars, are laid, partly in and partly out of the chests, but in such a manner that they can be drawn out when required. To prevent access of air to the chest, the rest of the opening is carefully filled up with fine ashes, well rammed in. The man-holes and small openings are now made up as before mentioned; a fire of coals, which has been previously prepared, is put upon the grate at both ends, and will require constant attention day and night for six to eight days. The fire is raised gradually, and the intensity of it regulated solely by the experience and judgment of the converter.

The coal suitable for converting is such as will burn away in a good draught, leaving scarcely any residuum but white ashes, which fall between the bars into the ash-pit. That coal which in burning runs together into a mass of large cinder would not do at all, because in that state it would stop the draught from passing between the grate-bars through the fire. Each firing will take from 4 to 5 cwt. of coal, and will require renewal every 2½ or 3 hours; and a heat of steel converting will require, on the average, 12 to 13 tons of coal or more, according to the size of the furnace and the time required.

A furnace of the size generally preferred will hold from 16 to 18 tons of iron. In larger furnaces the steel cannot be so equally converted; and in smaller the conversion costs more a ton. The iron is considered to gain about 4 lbs. to the ton in this process; but this will depend upon the kind of heat used, whether a mild one for springs, or a hard one for melting; but, after all, the gain in weight must only be regarded as an approximation.

When the fire has been continued so long that the degree of conversion desired is supposed to be nearly attained, one of the tap-bars is drawn out—the opening stopped up. When cold, the bar is broken; and by its appearance a judgment is formed of the state of the whole, and the firing regulated accordingly. In a few hours more a second bar is drawn, and the progress made in the interim observed; this is a further guide for the continuance of the fire for some time longer, or for allowing it to go out, as the case may require.

The whole quantity put into a converting furnace at one time is called a heat of steel; and, according to the degree of carbonization required, it is called a spring-heat, a cutler's-heat, a shear-heat, a file-heat, or a melting-heat. When the fire is let out, the furnace requires no attention for three or four days. By that time the man-holes may be opened to allow a draught of air through, to hasten the cooling; and in a few days more it will be cool enough for a man to enter, in order to break the covers off, and take out the steel, which is generally done while the steel is still too hot to be taken out with the bare hands. The men's hands are protected in doing this by several thicknesses of coarse cloth. Some of the charcoal, when the small dust is sifted from it, will be fit to use again mixed with fresh charcoal.

Steel obtained by this process is never quite equally converted. Near the bottom and sides of the chests it is more carbonized than in the middle; and this is true also of every single bar, the external being more converted than the internal parts. The bars are also covered with blisters; this gives rise to the appellation, blistered steel.

The blisters are doubtless owing to some impurities in the iron, which in the furnace take the gaseous form, and raise the blisters by the force of their elasticity. What those gases are is unknown; but it is known that, whatever the impurities, they are got rid of in the crucible of the melting furnace when bar steel is made into cast steel.

Bessemer Process.—The most recent and advanced practice in the working of this process was fully described in a lecture given in the United States by Alex. L. Holley, and to his lecture we are greatly indebted for the following particulars.

The Bessemer process as first performed, and as still practised to a very limited extent, with irons rich in manganese, consists in applying the blast until all but ¼ to ½ of 1 per cent. of the carbon is burned out, and then casting the product. Stopping the blast at this point, however, is very uncertain; hardly any irons contain the right amount of manganese for this treatment, and the process has certain mechanical objections. Hence the nearly universal practice is to blow the iron until all the carbon is exhausted, a point readily determined. But the product now contains so much oxide of iron, that it is red-short and crumbles in working. To reduce this oxide of iron, manganese, which has a stronger affinity for the oxygen than the iron has, is added, by running into the converter 6 to 8 per cent. of melted Franklinite, or spiegeleisen, which is a pig iron containing about 10 per cent. of manganese. One quarter to 1 per cent. of carbon is also added to the product by the spiegeleisen, so that the result is the same as in the first process, and the convenience and economy are far greater.

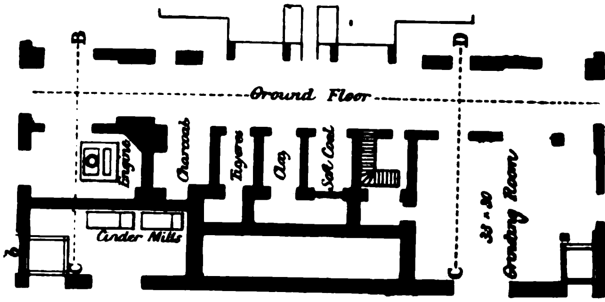
No phosphorus whatever is removed from the iron in the Bessemer process, and only 12 to 15 hundredths of 1 per cent. of phosphorus are admissible in steel. More will make it both brittle and unmalleable. Hence the pig iron treated must not contain above one-tenth of 1 per cent. of this element. The usual percentages of sulphur, manganese, silicon, copper, and the foreign elements commonly found in average pig iron, are admissible. Suitable ore for Bessemer iron is unlimited in the Lake Superior and Missouri Iron Mountain regions, and is now developing

abundantly in Northern New York, Central Pennsylvania, and at various points in the Southern States.

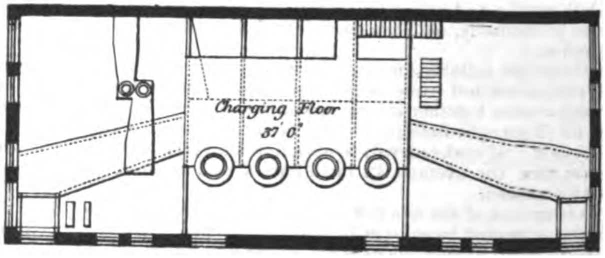
A standard American Bessemer plant has a melting department. This is shown in plan, the ground floor by Fig. 6994, the furnace working floor by Fig. 6996, and the cupola charging floor by Fig. 6995. Fig. 6997 is a section at A B, Fig. 6994; and Fig. 6998, section on E F, Fig. 6996. There are hoists at *a* for coal, and at *b* for iron; four cupola furnaces and their platforms and blowing machinery; two ladles K standing on scales, for weighing the melted iron, and spouts M, N, Fig. 6998, for conducting it to the vessels, or converters; two reverberatory furnaces for spiegeleisen, and their spouts.

The converting department, shown in ground plan by Fig. 6996, and in cross-section by Fig. 6998, contains two 5-ton to 7-ton vessels N, in which the

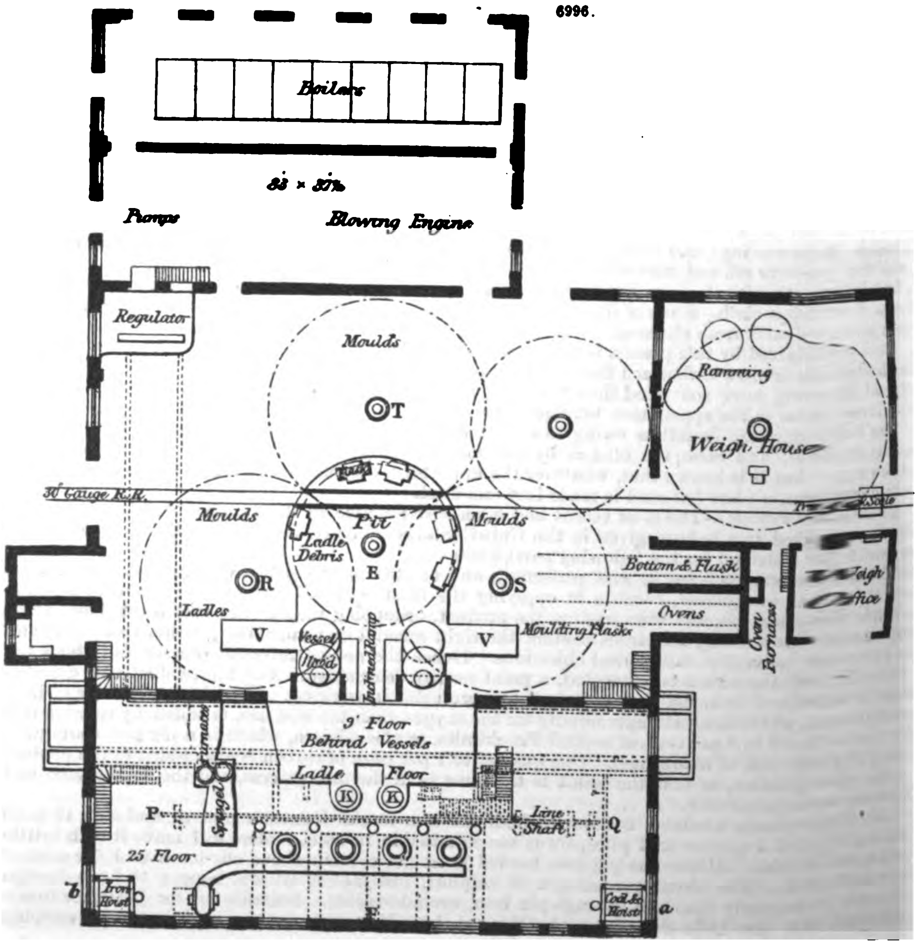
6994.



6995.



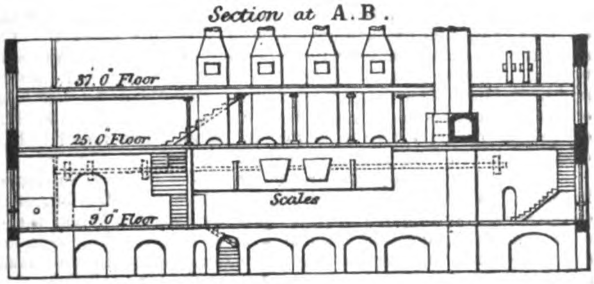
6996.



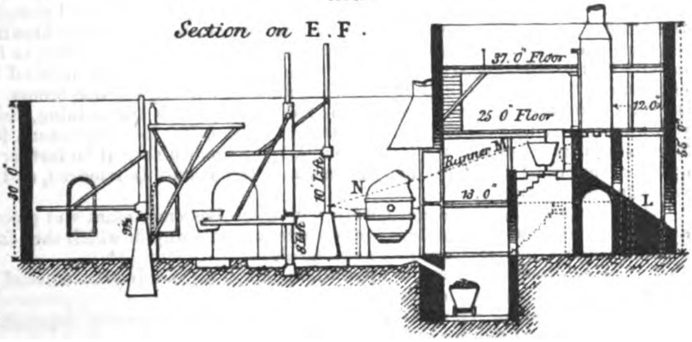
melted iron is treated by air-blasts. Also a ladle and a hydraulic ladle-crane at E, Fig. 6996, by means of which the steel is received from the vessels and poured into the ingot-moulds, which stand upon a depressed part of the floor called the pit. Three other hydraulic cranes swing over the pit, to set the ingot-moulds and remove and load the ingots. Two of them swing over the vessels, to assist in their daily repairs. The water and air pressure reservoirs are surmounted by a platform, Fig. 6998, standing upon which, boys, by turning valves, admit water to the cranes and air to the vessels, by means of underground pipes. All the constant operations of hoisting, lowering, and blowing are conducted from this platform, which overlooks the entire converting department. The details of these and other parts will be further described.

The engine department contains a blowing engine, usually a double engine, capable at normal speed of receiving 8000 to 11,000 cub. ft. of air a minute, and delivering it at 25 lbs. pressure on the square inch. The water-pressure pump, for actuating the hydraulic machinery, is a Worthington duplex, with two 25-in. steam-cylinders, and two 9-in. water-cylinders, 24-in. stroke. The boilers should be capable of 800 horse-power.

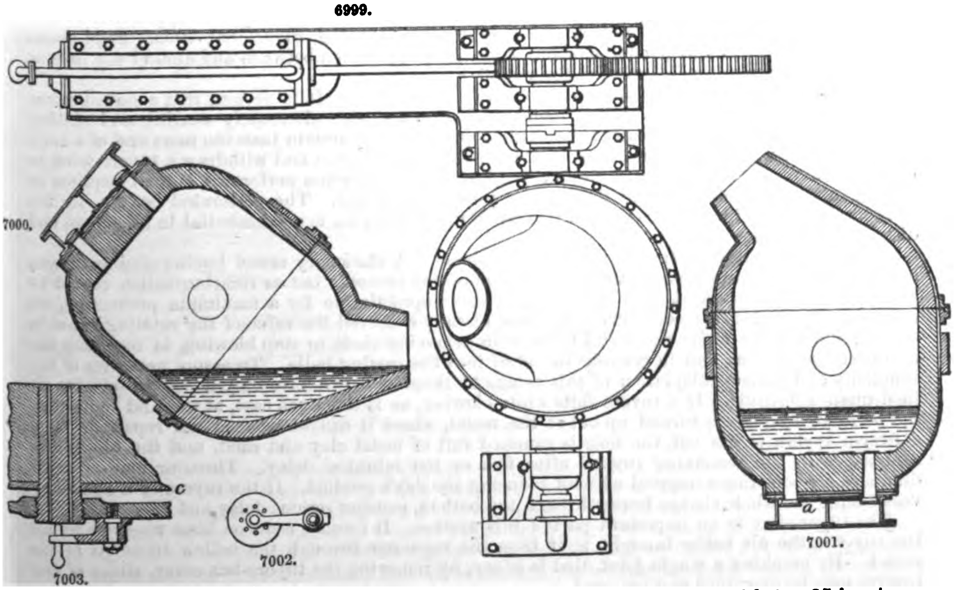
6997.



6998.



6999.



7000. 7001. 7002. 7003.

The pig iron, having been hoisted to the charging platform, is put, with 20 per cent. of coal, into one of the cupolas, and melted. When say 12,600 lbs. have run into one of the ladles K, the latter is turned over by means of a worm-wheel, thus pouring the iron into the spout which leads it to one of the vessels.

Before following the iron through the converting process, let us glance at the construction of the vessel, of which Figs. 6999 to 7001 are the simplest form. A vessel that will convert a 5-ton

charge is $8\frac{1}{2}$ ft. in external diameter, and 15 ft. high. It is made chiefly of $\frac{1}{2}$-in. to $\frac{5}{8}$-in. iron plates, and lined nearly a foot thick with refractory material. At one end it has an 18-in. opening, called the nose; at the other a tuyere-box *a*, Fig. 7001, communicating with the blowing engine. From the tuyere-box, twelve fire-brick tuyeres, each perforated with twelve $\frac{3}{8}$-in. holes, project through and are imbedded in the lining. A tuyere is shown in section by Fig. 7003. These tuyeres last but six or eight heats, and are arranged so as to be rapidly renewed. The vessel is mounted on trunnions, and turned by a hydraulic cylinder, by means of a rack and pinion. When the charge enters, the tuyeres are turned up, Fig. 7000, so that the iron will not run into them. The blast is then admitted, and the tuyeres turned down so that the metal will flow over them and be pierced by the entering columns of air. The cubical contents of the vessel is eight to twelve times that of a charge of iron, in order to give room for ebullition. The vessel lining is heated red hot, and the fuel discharged before the iron is turned in.

The iron is now subjected to 120 streams of air, $\frac{3}{8}$ in. in diameter, at 15 lbs. to 25 lbs. pressure, for about twenty minutes. Most of the silicon is first burned out, the result being slag, and a comparatively dull flame at the converter mouth. When the carbon begins to burn freely, the volume and brilliancy of the flame increase, and as the surging mass grows hotter, and boils over in splashes of fluid slag, the discharge is a thick, white, roaring, dazzling blaze, and the massive vessel and its iron foundations tremble under the violent ebullition.

Towards the close of the operation the flame becomes thinner, and when decarburization is complete, it suddenly contracts and loses illuminating power. The determination of this period is the critical point of the process. Ten seconds too much or too little blowing injures or spoils the product. At the proper instant, as determined best by the spectroscope, or by coloured glasses, but usually by the naked eye, the foreman turns down the vessel and shuts off the blast. The charge of melted spiegeleisen is then run in, when another flaming reaction occurs. The vessel being still further depressed, the steel runs into the ladle, pure, white and shining, from under its coating of red-hot slag. A blanket of slag, most useful in preserving its temperature, follows it into the ladle. The metal is now led into the ingot-moulds, by means which will be further illustrated. After the exterior surface of the steel has crystallized, the mould is removed, and the ingot is ready for reheating and rolling.

Having thus taken a general observation of the Bessemer plant and process, we are prepared to analyze the peculiar mechanical requirements, and the way in which they have been met.

This subject divides itself under two heads;—

1. The cardinal requirements upon which hinge the production of steel at all, whether fast or slowly, expensively or economically.

2. The mechanical refinements, upon which commercial success depends.

The first radical feature of the Bessemer apparatus was imbedding the tuyeres in the lining of the vessel; or, in other words, the perforation of the bottom part of the vessel lining. The bottoms of the tuyeres are luted with plastic clay, inserted in openings in the tuyere-box, grooved to hold the luting, so that no air can leak by, and held in place by a dog, Figs. 7002, 7003. Semi-plastic refractory material, chiefly ground silicious stone, is then rammed between and around the tuyeres, thus forming the continuous lining of the vessel.

This feature is essential to the maintenance of the tuyeres. It is obvious that a naked refractory tube, projecting into the molten metal, with iron and slag alternately wearing and chilling on all sides of it, is far more costly to construct, operate, and maintain than the mere end of a brick block lying flush with the lining, and that any apparatus to insert and withdraw a tuyere must be expensive and easily deranged by the heat and splashes, while the perforated bottom requires no moving apparatus additional to that which rotates the vessel. The perforated bottom, for the introduction of the blast beneath the iron and in numerous jets, is also essential to its violent and distributed agitation.

The second radical feature is the rotating vessel. A stationary vessel having similar tuyeres met with a very limited use at the introduction of the process; but as recarburization cannot be performed in such a vessel, and as it is otherwise impracticable for a maximum production, we may properly omit its consideration. We have already observed the value of the rotating vessel in placing the tuyeres under the metal to blow, in removing them to stop blowing, in receiving the iron from the cupolas, and in pouring the steel into the casting ladle. To assure ourselves of the simplicity and perfect adaptation of this means to these ends, we have only to try to imagine an inadequate substitute. If a tuyere fails while blowing, as is often the case, at the first indication, the perforated bottom is turned up out of the metal, where it can be reached and repaired. The defective tuyere is cut out, the hole is rammed full of moist clay and sand, and the blowing is resumed with the remaining tuyeres after five or ten minutes' delay. Three or four of these dummies are sometimes inserted without reducing the day's product. If the tuyere of a stationary vessel fails, the whole charge burns through the bottom, causing serious delay and loss.

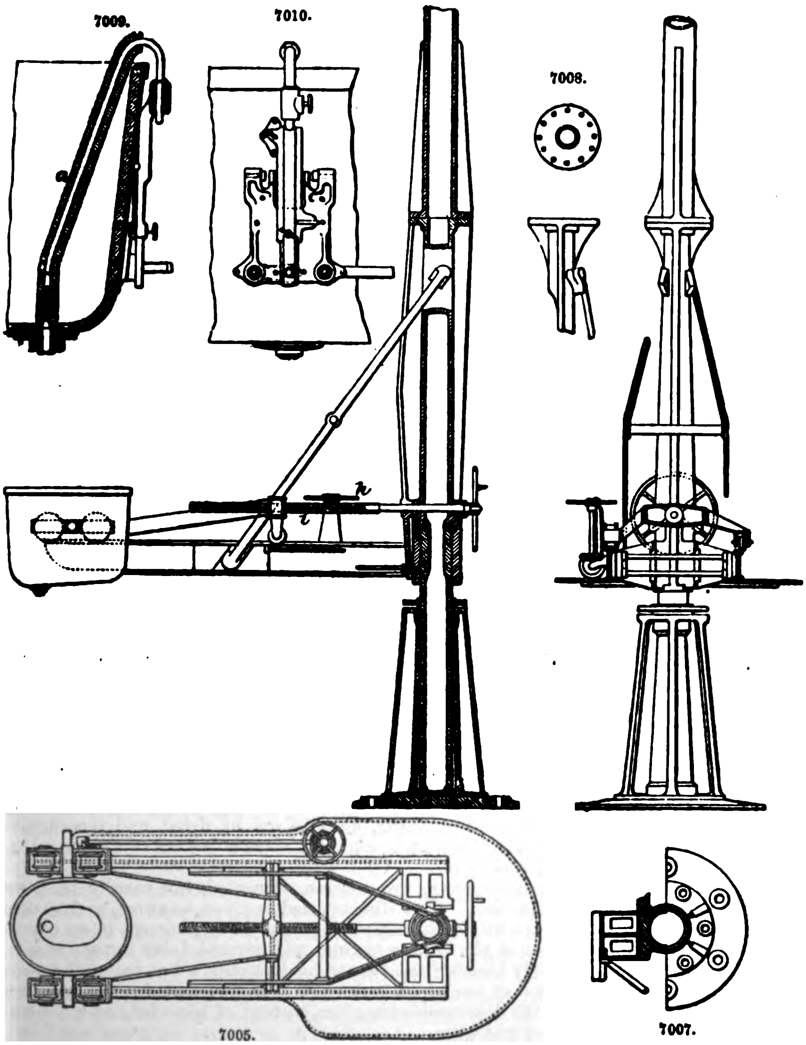
The tuyere-box is an important part of this system. It forms a common blast reservoir for all the tuyeres, the air being brought to it from the regulator through the hollow trunnion of the vessel. By breaking a single joint, that is to say, by removing the tuyere-box cover, either of the tuyeres may be examined and removed.

One of the neatest of Bessemer's minor inventions is the air-space *c*, Fig. 7003, left between the top of the tuyere-box and the bottom of the vessel. If any blast leaks by a tuyere, it escapes into this passage instead of cutting a channel clear through the lining alongside the tuyere; or if a tuyere burns down too short, the sparks escaping through this air-space apprise the workman in time to turn down the vessel before serious damage is done.

The shape of the vessel is an important feature. The interior is well formed for resisting wear, for thorough agitation, and for the preservation of heat. The nose is equally convenient for charging and discharging the metal, and for discharging the gaseous products of combustion into the chimney. The angular position of the nose gives the vessel so large a capacity when lying on its

side, that the whole charge will lie in it without running either into the tuyeres or out of the nose. We can hardly see how the shape can be improved, or how any other would be admissible. In its general features it was the first, and as here presented it was the second vessel introduced by Bessemer.

The ladle-crane, Figs. 7004 to 7008, is another radical departure from the nearest kindred



7009. 7010. 7004. 7008. 7006. 7005. 7007.

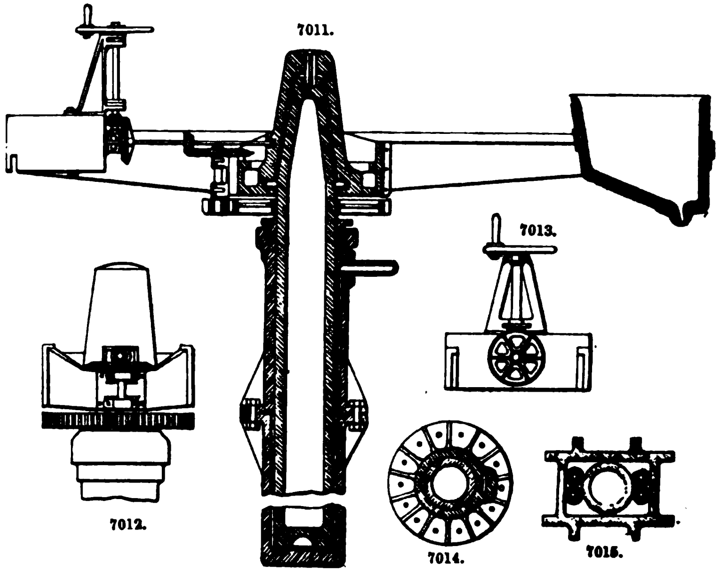
practice. The ladle, instead of swinging from a crane chain, as in a foundry, is rigidly held in a fixed orbit. This feature was original with Bessemer, and to it he added the old ladle with a pouring nozzle in its bottom, regulated by a movable stopper. This consists of a loam-coated rod *a*, Fig. 7009, armed at its lower end with a round-ended fire-brick or plumbago stopper, fitted to the concave top of a fire-brick nozzle. The stopper is raised and lowered by a lever *e*, Fig. 7010, in the hand of the workman. Thus the heavy steel is discharged pure, while the lighter slag and impurities are left at the top. Pouring steel into moulds over the rim of a ladle, as in foundries, would make excessive scrap from spilling and chilling, and is wholly impracticable. The vertical motion of the crane is necessary in pouring from the vessel, to keep the ladle close under the nose, thus preventing too great a fall of the stream and consequent slopping. The ladle is also tipped by a worm and worm-wheel *h*, Fig. 7004, to regulate the position of the nozzle over the moulds, and to turn over the ladle for heating and repairs.

The radial motion of the ladle, by means of a rack or a screw *i*, is necessary to adjust the stream vertically into moulds standing in different positions; and it is convenient in properly placing the ladle under the vessel's nose.

Again, the accurate adjusting of the stopper in the nozzle is effected by means of a hinged plate,

Figs. 7009, 7010, to which the stopper, slide, and lever are attached. These latter features are peculiarly American.

Figs. 7011 to 7015, the English ladle-crane. The ram has no top support. The jib revolves on friction-rollers, and the weight of the ladle is counterbalanced. The details of construction will be further referred to.



7011. 7012. 7013. 7014. 7015.

A very large and regular product is essential to commercial success in the manufacture of steel. The same engine and boiler capacity, the same vessels and accessories, the same quality and nearly the same extent of hydraulic machinery, melting apparatus, and buildings, are required to make six 5-ton heats a day as to make sixteen 5-ton heats a day. Six heats was the maximum work in England a few years ago, and still is in some foreign works, ten or twelve being the general average, while eighteen to twenty-four heats are the standard practice in America. This additional work, got out of nearly the same capital, is the result of these mechanical refinements.

In order to obtain with Bessemer machinery the maximum production, its strength and durability must be implicitly relied on. No weakness, irregularity, or inefficiency can be tolerated. The failure of one little part may involve a whole system of machinery in costly delays and extensive repairs.

Two vessels are simply indispensable. If a set of tuyeres will only endure four to six heats, and a new set, together with its section of vessel lining, must be put in, dried, and thoroughly heated before it can be used, it is easy to see that getting eighteen heats a day out of one vessel is beyond the present capacity of refractory materials.

A double blowing engine, that is to say, two engines connected, has usually been preferred, but is not indispensable to uniform blast. Two disconnected engines, however, as first used at the Cambria Steel Works, in Pennsylvania, each engine large and strong enough in an emergency to blow a heat, give the advantages of the double engine, and prevent delay in case one engine is disabled. Nor is this all. Merely blowing say twenty heats occupies but ten of the twenty-four hours, yet the engine must run ten or twelve hours besides this, at reduced speed and pressure, to heat the vessels. Using one of the disconnected engines, instead of the whole of a double engine, for this purpose, saves much steam and wear.

The pressure pump, for actuating the hydraulic machinery, is the heart of the Bessemer system. If the heart stops, trouble is serious and immediate. Two pressure pumps are deemed essential to maximum capacity. Two cranes are necessary to reach over the two vessels; three are indispensable to a product of 80 or 100 tons a day. Three cupolas are necessary to give time for the repairs of their linings, although but one is run at a time. Four are used in the latest plants. Two spiegel furnaces are employed for the same reason.

This and some further duplication of machinery is essential, not only to continuous working in case of breakdowns, but to the simultaneous conduct of manufacture and repairs.

It will have been observed that in handling melted iron and steel on this large scale—handling it so carefully as to prevent spilling, and so rapidly as to avoid chilling—requires not only strength of parts, but great steadiness and celerity in the operations, and absolute control of them by the workmen. This almost necessarily involves the use of hydraulic machinery. A steam hoist, a simple cylinder and piston, is wholly inapplicable, by reason of the elasticity, condensation, and consequent unsteadiness of the steam support. A steam hoist geared, to overcome this difficulty, is liable to be disabled by heat, splashes of slag and metal, and showers of sand. Nothing can be more simple and permanent than a massive hydraulic cylinder and ram. Water being practically unaltered in volume by any temperature or pressure to which it is here subjected, its motion can be

controlled with the utmost nicety, and its staying power, when placed, is like that of a cast-iron column.

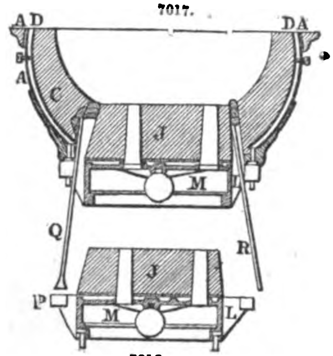
The difficulty of repairing the refractory linings, especially the vessel's bottom, which lasts only four to eight heats, was for a long time the weak point of the Bessemer system.

The early method of setting tuyeres was knocking out the stump left from the denudation of the bottom, and inserting a new tuyere from the tuyere-box. The vessel being too hot to enter for twenty hours or more after a blow, for the purpose of filling and ramming the space around the tuyeres, this space could only be filled by pouring semi-fluid refractory material into the nose of the vessel, and letting it set as best it might by the evaporation of the water. The bottom was thus porous, and, unless long heated, it was damp. The constant breaking through of the steel was the result.

Bessemer then devised the duplicate bottom, Fig. 7016, consisting of a tuyere-box, tuyeres, and section of lining, previously rammed and dried. The old bottom, with its tuyere-box, was withdrawn bodily, and the new one inserted. This was a vast improvement; but still the annular space around the new bottom had to be filled with a semi-fluid material, just like the space around the individual tuyeres in the old practice; or else the vessel had to stand idle a long time to cool, so that a workman could enter it and ram the joint.

7018.

7017.



7016.

After a good deal of experimenting, the simple expedient was arrived at in America of so constructing the lower part of the vessel, as at D, Figs. 7017, 7018, that the annular space can be rammed from the outside with bricks or cakes of semi-plastic material. The method of inserting this filling, by means of the rammers Q, R, into the annular space K, between the new bottom and the vessel lining, is shown in Fig. 7017. The filling is then covered with the plates N, Fig. 7018, which are cottered on; after half-an-hour's heating the vessel is ready for use. A new, dry, and trustworthy bottom can now be made in two hours from the last blow on the old bottom, so that one vessel is always ready. Six interchangeable bottoms are employed for two vessels. This seems a small detail, but it has been the chief cause of raising the product of American works from ten and twelve to eighteen and twenty-four heats a day, and it has nearly done away with what was sometimes of daily occurrence in the old practice—the bursting through of the fluid metal, often so suddenly and on such a scale as to render temporary repairs impossible, so that the whole charge was made into scrap.

The lining of the vessel other than the bottom, with the best American refractory materials yet employed, endures 400 to 500 heats. The best English materials last twice as long.

The English vessel lining is a hard sandstone, called ganister. It contains about 93 per cent. of silica, 4 per cent. of alumina, 1 or 2 per cent. of oxide of iron, and often a little soda, lime, potash, and other substances. It is a true quartzite. This is ground into sand and dust, and mixed, sometimes, but not always, with a little fire-clay while being ground. It is then wetted to a semi-plastic consistency, and rammed into a solid wall, between an iron mould temporarily inserted and the shell of the vessel. The hardness and uniformity of the ramming is of special importance. The lining is at first slowly dried, and then glazed by half filling the vessel with coal, and blowing for four to five hours at 2-lb. to 3-lb. pressure. The vessel is then ready for use.

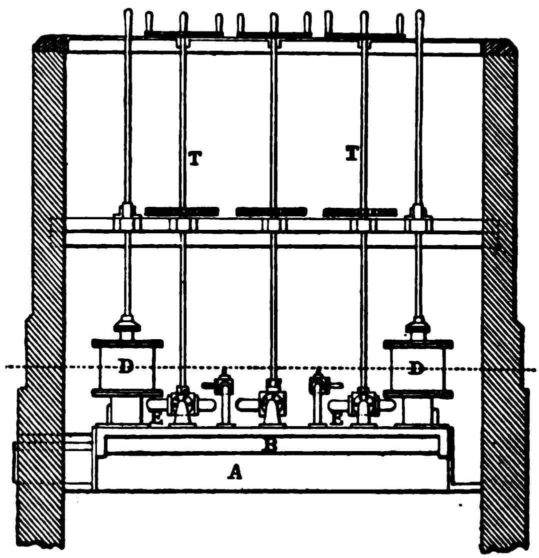
In the United States no stone exactly like ganister has yet been found. Any hard, dense sandstone, or any quartz, mixed with 10 or 12 per cent. of ground fire-clay, is used. The chemical composition of many of these stones is similar to that of ganister, except that they contain a little less alumina. The natural mixture of the small amount of alumina in ganister appears to give the mass a degree of density and cohesion, both wet and dry, that can hardly be obtained with three or four times the amount artificially mixed. Too much alumina is chemically eaten away; this is why tuyeres fail so soon. A fire-brick vessel lining, though hard enough to stand the abrasion of the surging mass, would be chemically destroyed in a very few heats. Silica, on the contrary, although refractory enough, is soon washed away, because it will not fuse into a dense mass. The mechanical structure of quartzite has an important bearing on its endurance when rammed into the vessel. The heat of successive charges compacts and hardens it.

In order to place the moulds in the vessel so that the lining material can be rammed around them, the vessel must be taken apart. In many works, the vessel is divided near the centre; each section is turned with its larger opening upward, and separately rammed. The two are then put together with a luting of fire-clay; the whole operation occupying thirty-six to forty-eight hours.

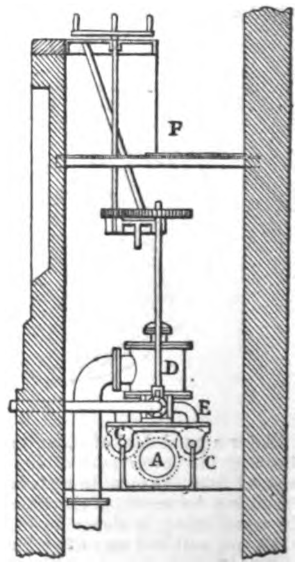
The American plan, just being introduced, is that of duplicate top, bottom, and nose sections, which are previously rammed and dried. The centre section, being more difficult of removal, on account of the trunnions, is rammed in its place. The time lost in lining is thus brought down to about twelve hours.

The regulator before referred to, Figs. 7019, 7020, is a raised platform F over the air and water distributing apparatus, standing upon which workmen can observe and regulate all the motions of the vessels and cranes. The necessity of concentrating these operations at a point out of reach of the working heats of the vessels, and the flying splashes in case of accident, will be obvious. The construction is explained by the drawing. The air-chamber A communicates with the blowing engine; the water and exhaust chambers C with the pressure pump. D, D, are the air-valves for admitting the blast to the vessels; E, E, the 3-way and 4-way valves, constructed like gas-cocks, for distributing the water pressure to the hydraulic cylinders. Their construction is shown by Figs. 7023, 7024. This is Bessemer's early regulator. A larger number of valves, and many improvements in detail, have been added.

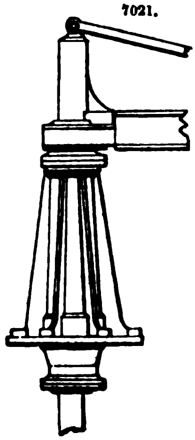
7019.



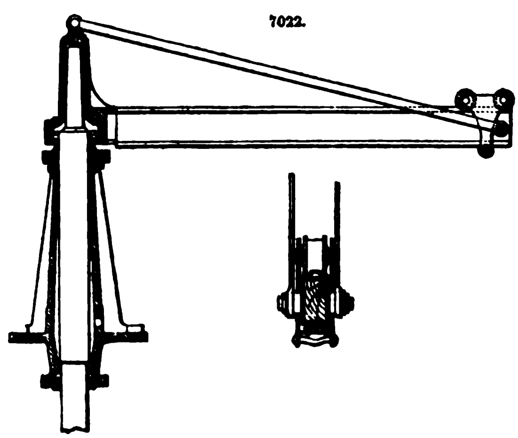
7020.



7021.



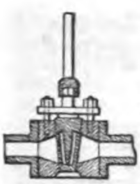
7022.



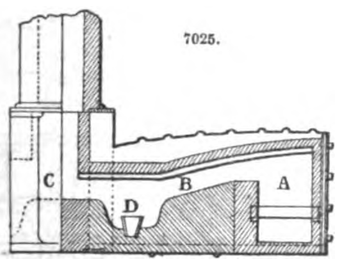
The English form of ingot-crane is illustrated by Figs. 7021, 7022. All hydraulic cranes used in Bessemer works consist of a vertically moving ram, to which a horizontal jib is attached. In ordinary cranes the jib does not move vertically, which is a serious comparative disadvantage, because all radial transference of the load must be done by racking the jib-carriage, from which the load is suspended, backwards and forwards by slow-moving gearing or pulleys. When a jib rises and falls, its carriage may be moved radially by simply pushing the load; the carriage runs on the jib, just like a car on a railway, unhampered by sheaves and chains. Bessemer's crane, Figs. 7021, 7022, consists of a cylinder containing a ram of two diameters, the smaller end passing through a bottom stuffing box, and the larger through an upper stuffing box. To the upper end the jib is attached.

The difference in cross-sectional area between the two ends of the ram is the area acted upon by the water to lift it. The lateral strain of the overhanging jib, on the upper end of the ram, is very great, requiring excessive strength; and its friction in the stuffing box is so severe that the ram often chatters in rising, and the jib can only be turned in its orbit by means of the independent head revolving on rollers. The foundation must be hollow to get at the lower stuffing box, and very solid and wide to keep the whole structure from tipping over.

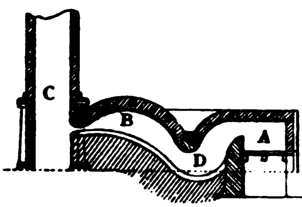
7023.



7025.

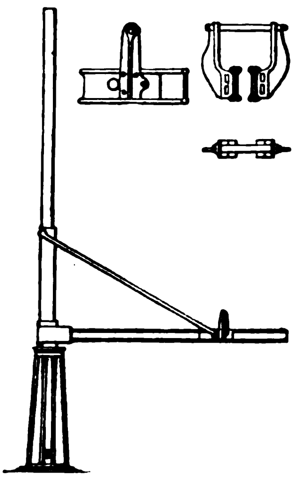


7024.



7026.

7027. 7028. 7029.



The crane generally used in American works, Figs. 7027 to 7029, consists of a cylinder, open at the top only, and requiring chiefly vertical support from the solid pier on which it rests. The ram passes through an upper stuffing box, and through a top support in the roof of the building. The jib is placed between these supports, so that the lateral strain on the ram is comparatively small. This is illustrated by the fact that no rollers are required; the ram turns in the stuffing box. The jib of an 8-ton crane can be pulled round its orbit by one hand. The ram is stepped upon a column of water which is substantially frictionless. The top support has proved itself convenient, and economical of power and repairs; and, after counting the cost of the supports in the roof, this system of cranes is less costly than Bessemer's system.

The amount of the hydraulic pressure employed has been regulated chiefly by the proportions of the crane; that is to say, it was found that for an 8-ton crane, having a 10-ft. lift and 22-ft. jib, a 13-in. ram was well proportioned for strength. Adding friction and fluctuations of pressure, it was found that 300 lbs. an inch on this 13-in. ram was abundant for all emergencies, and the working pressure has been fixed at about this point, instead of being carried to 1500 lbs. or more, as is so usual in other hydraulic machinery. The comparative durability of valves and packing under the low pressure is very great.

Hydraulic pressure is applied to the ordinary form of crane, and also to the lift for raising charges to the cupolas, by means of a simple cylinder, the piston-rod of which pulls a chain. The length of the lift may be made two, three, or more times that of the piston, by interposing pulleys, that is to say, the ordinary block and fall reversed.

The 4-way cock, Figs. 7023, 7024, that distributes the water to the lift-cylinder, is actuated by a hand-chain within convenient reach of the workmen on the various floors. The advantages of this lift over any geared or belted lift, unless complicated by brakes, are, first, that it cannot overrun. When the cage is as high as it should go, the piston is at the end of the cylinder, and can go no farther. Secondly, the control of the rate and extent of motion is much better, as it consists in partly or wholly closing a cock, instead of wholly shifting a belt. Thirdly, the repairs of such a lift, properly constructed, are hardly appreciable, compared with the maintenance of belts and numerous and rapidly moving parts.

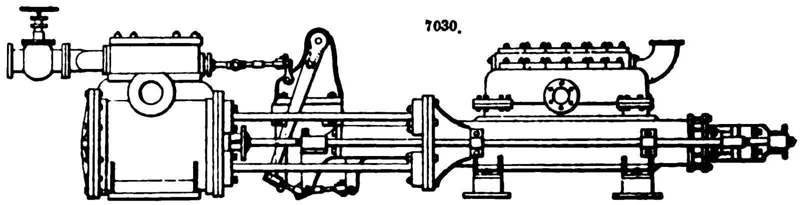
The important features of the Worthington duplex pressure-pump are generally illustrated by Figs. 7030, 7031. The duplex system, the movement of the steam-valve of one engine by the piston of the other engine, permits the water-pistons to stop, momentarily, at the ends of their stroke, thus allowing the water-valves time to seat without slamming. This feature also causes uniformity of pressure, and the absence of the fly-wheel gives the pump all the other advantages of the Cornish engine.

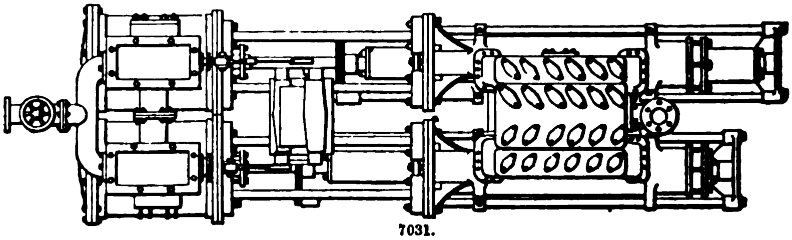
Each water-engine, instead of being a cylinder bored from end to end and fitted with a piston, consists of two separate cylinders, bored in the throat only, and fitted with two plungers, connected together. A stuffing box around a plunger is much more easily kept tight than the packing of a piston, especially when the latter has a variable stroke and tends to wear and enlarge the middle of the cylinder, particularly at the bottom, where sediment collects.

The water is pumped into an accumulator, consisting of a cylinder and weighted ram like those of a crane. When the cylinder is full, it nearly shuts off the steam from the pump by means of a lever and throttle-valve. This arrangement saves some steam, and prevents the pump from running too fast when several cranes happen to be started at once.

Safety-valves for pressure and feed pumps are abandoned, it having been found better to make the parts strong enough to resist the full force of the steam. When the water exit is shut off, the

7030.





7031.

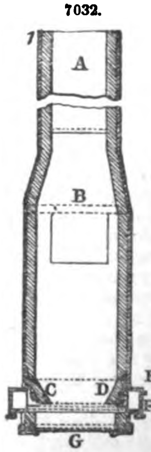
pump simply stops, under pressure. The packings heretofore employed for the glands and pistons of hydraulic machinery have been leather cups, which are not very durable, and, when large, are quite costly. The Martin packing, consisting of a roll of hemp-tape forming a continuous ring, and covered with wire cloth on the wearing surface, has been lately adopted, with excellent results.

In the melting department some interesting and important changes have been made. The reverberatory furnace was, until recently, employed for melting the principal charge, and is still used in the United States for the spiegeleisen charge; because, as this is small and often has to be held for some time after melting, the flame of the reverberatory constantly playing over it prevents its chilling. The very oxidizable manganese in the spiegeleisen is also more affected by the blast of the cupola than by the comparatively neutral flame of the reverberatory.

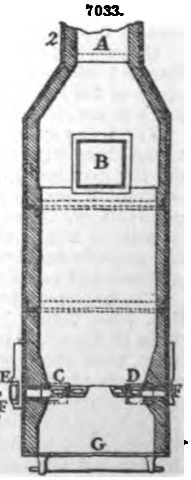
In the older form of air-furnace, Fig. 7025, the flame and any free air it may contain are drawn from the fire-box A along the roof of the furnace, and do not come into very direct contact with the metal lying at B; hence this form is best employed for melting the spiegeleisen. Fig. 7026 shows a later form of furnace, which melts faster because the flame is thrown directly upon the metal lying at B; but it also oxidizes the metal more rapidly. It was first employed for melting the principal charge, but as it required three hours and 2½ tons of coal to bring down 5 tons of iron, it was early abandoned for the cupola, which melts a 6-ton charge in less than one hour with 1 ton of coal.

Adapting the cupola to the Bessemer manufacture has, however, required some costly experimenting. What was considered the best foundry cupola—MacKensie's, Fig. 7032—was first employed; but it would only melt 20 or 30 tons. The shallow bottom then filled with slag, which choked the tuyeres and scaffolded above them. The present cupola, Fig. 7033, melts 100 tons in eighteen to twenty hours.

7032.



7033.



The foundry cupola is made large enough to melt what is required in two or three hours; the hearth is left shallow to take the least amount of fuel, for the bed of coal must reach above the tuyeres, however little iron is melted. And the day's work is over before slag accumulates to any embarrassing extent. But the Bessemer cupola must deliver 6 tons an hour, at the highest attainable temperature, for a whole day and night. There must be a deep hearth or receptacle for slag under the tuyeres, and an upper tapping hole by which the slag may be worked off as in a blast furnace. The tuyere area must be excessively large to ensure ample air admission in case of partial chilling at any point; and the size, shape, and arrangement of tuyeres must be such that they can be conveniently got at, cleaned, and changed without stopping the operation.

A cupola for a 5-ton plant is of 5 ft. internal diameter and 14 ft. high; it has six oval tuyeres of 5 and 8 in. diameter. The boshes, so prominent in the MacKensie cupola, are reduced to prevent scaffolding. The MacKensie annular tuyere, however valuable in foundry practice, is not adapted to long-continued heats, because it cannot be conveniently cleaned from without, while working.

After the last charge is tapped out, the Bessemer cupola bottom is dropped, in the usual manner, to discharge the remaining débris. The most trustworthy cupola blower for the pressure here required, not less than 1 lb. an inch, is undoubtedly a light reciprocating engine, like a blast-furnace blowing engine. To give the required volume, 6000 cub. ft. a minute, such an engine is

rather costly. After much unsatisfactory experimenting with rotary pressure blowers, several American works have adopted the comparatively cheap Sturtevant high-speed fan-blower, with marked success.

Interposing ladles between the cupolas and vessels is important in many respects. The cupola cannot be so economically and regularly worked if its hearth has to fill up with the whole 12,000-lb. charge of iron every hour. The weight of the charges should be somewhat uniform, to promote uniformity and accuracy of blowing and to recarburize with a fixed percentage of spiegeleisen. This can only be accomplished by weighing the charge between the cupola and the vessel; and the ladles are placed on scales for this purpose. Several charges are often run into the ladles when the converting department is not ready for them, otherwise the cupola would have to be dumped, and part of a day's work lost.

Bessemer Process in England.—The iron almost exclusively employed in England for this process is obtained from the Cumberland district, and is derived from red hematite ores. The analysis of specimens of these ores is given at p. 2034.

The fuel used at the blast furnaces in the Cumberland district is the best Newcastle coke, which is remarkable for its hardness and freedom from sulphur. The percentage of sulphur is about 0·8, and of ash 4·45. No charcoal pig is made in England for the Bessemer process. The fluxes employed are a limestone quite free from phosphorus, and a portion of black shale from the coal beds, consisting of clay and carbonaceous matter without any appreciable amount of sulphur. The ores are not calcined. As it is necessary that the iron should be as grey as possible, not less than 30 cwt. of coke are used to each ton of iron produced.

Forest of Dean iron, made from brown hematite ores, is frequently used in small quantities in admixture with other irons for the purpose of maintaining the heat of the charge, which it tends to do. It is apt, however, to contain too large a percentage of sulphur to work well alone.

Another brand which is said to work well is Weardale, an iron made from spathic ores. It is unusually rich in manganese, and owes its excellence chiefly to that fact.

The pig iron used in the Bessemer process requires to be carefully selected; it has been stated, on authority, that the carbon in it should not be less than 3 per cent., silicon from 1 to 2 per cent., manganese not more than 3 per cent., and sulphur and phosphorus are limited to ·05 per cent.

The following analyses exhibit the characteristics of some of the more usual brands of iron employed;—

	Cleator.	Workington.	Weardale.	Forest of Dean.
Carbon (graphitic) ..	4·007	3·14	3·24	3·25
Silicon	1·752	3·12	1·80	1·36
Sulphur	..	0·05	0·04	0·037
Phosphorus	0·049	0·03	0·19	..
Manganese	..	0·02	1·45	..

The presence of silicon in the iron causes the charge to work hot in the converter, and it is usual therefore to mix an iron rich in this element with others containing a less quantity, and which have a tendency to work cold and become pasty. As a rule, Workington iron contains more silicon than any other in use for the process, and being moreover an excellent iron is largely used. It is, however, from the very fact of its working so hot, seldom employed alone, as it cuts the moulds badly in pouring.

Sulphur and phosphorus are the most injurious elements found in the pig, because the Bessemer process is powerless to remove them, and the quality of the steel is materially affected by their presence. An effectual means of eliminating these substances, in the process of conversion, would be a most valuable discovery.

It is usual among all the steel makers to mix several different brands of iron where a uniform and good quality of steel is desired, but there seems to be no definite mixture which is agreed upon as best. The principle appears to be to form the larger portion of the charge of the better brands of Cumberland hematite, and to add as correctives smaller percentages of other irons. The following will serve as examples;—

I.	
Workington	45
Harrington	40
West Cumberland	10
Wigan	20
Weardale	7
Forest of Dean	3
	120
Spiegel	7½
	127½

II.	
Cleator	40
Workington	20
Harrington (No. 1)	15
Harrington (No. 2)	5
Forest of Dean	10
Wigan	3
	93
Spiegel	6¼ or 6½

For forgings, such as axles, tires, or locomotive crank-shafts, none but No. 1 iron is commonly used, but for rails a greater or less amount of No. 2 is added, in order to reduce the cost as far as possible. The amount of this quality that may be used will of course depend on the character of the iron.

The percentage of manganese in the spiegeleisen should be equal to about twice the amount of carbon, the former having the effect of deoxidizing should the metal have blown rather too much.

It is important also to use a small quantity of flux, such as aluminous ore, limestone, or lime and broken fire-brick, in order to get a good fusible slag, otherwise *shots* of steel are suspended in the slag and lost.

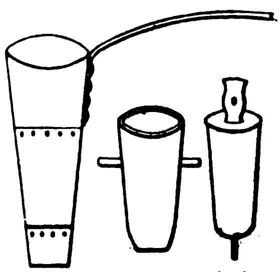
The iron as a rule is melted in reverberatory furnaces, but at some works cupolas have been substituted with apparently good results. Where cupolas are used, much greater care has to be exercised in the selection of the coke, as fuel which might be used in the air furnaces would destroy the quality of the iron if burned in contact with it. The opinion among those who employ the cupolas is, that it is quite possible to find a coke sufficiently free from sulphur to yield a satisfactory result. At the Barrow works, preparations had been made to convey the molten metal directly from the blast furnaces to the converters, but after a number of trials it was found that the uniformity of the metal could not be relied on, and, in consequence, the attempt was abandoned, and cupolas erected instead, to remelt the pigs. The converters at the majority of the works have a capacity adequate for a yield of 5 tons of steel, or allowing one-sixth for waste, which may be taken as a fair average, for 6 tons of molten iron. The material commonly employed for lining the vessels is ganister, a highly silicious substance, found at Sheffield. Other materials have been tried at some works, as, for example, at Dowlais, with apparently great success. A pair of vessels, at the works just mentioned, had, in 1868, stood 300 blows each, without relining, and were still apparently in good condition. This is much above the average endurance of the refractory linings.

The sizes of ingots most commonly cast are, for rails, about 10 in. square; for locomotive crank-shafts, ingots of a rectangular section, say 22 in. × 16 in.; and for other forgings, according to the size and nature of the work, the moulds having a weight about equal to that of the ingots. At some works the plan is adopted of testing a sample of each blow for carbon, and classifying the metal according to the result of this test. By this means much greater uniformity in the finished work is obtained, and in the present state of our knowledge of the process, this is a very necessary means to secure this end, and should be more generally adopted. The process employed was introduced from Sweden, and is exceedingly simple in its nature. It consists in dissolving a known weight of metal, in the form of drill chips, or some other finely-divided state, in nitric acid, of the gravity 1·2. The solution will have a brown colour, more or less deep, according to the percentage of carbon contained in the metal. A standard colour, corresponding to a known percentage of carbon, as determined by direct analysis, is first established, and the colour of the solution to be tested is made to agree exactly with this by the addition of a certain quantity of acid or water. That this, which is the readiest method of producing agreement, may be employed, the colour of the standard solution must be light. The water is added to the solution in a graduated test-tube, so that the exact proportion of water relatively to the original solution may be read off with ease; and if, for example, an equal bulk of water requires to be added to make the colour the same as the standard, the percentage of carbon in the specimen under test must be just double that of the standard. As a solution of steel in acid would in the course of time change its colour, an exact imitation of it is made by dissolving burnt sugar, and this is kept hermetically sealed for comparison. To secure a light standard colour, it is not necessary that the piece of steel dissolved should contain a small percentage of carbon; but a larger quantity of acid may be used in a known proportion, say twice or three times the required amount, and the corresponding percentage of carbon will be equally well ascertained. This test is easily and quickly applied, and the variation of colour being considerable, gives results sufficiently accurate for the purpose of a proper classification of the ingots, according to the purposes for which they are suited.

The principal uses to which the Bessemer metal is put in England are the manufacture of rails, tires, axles, machinery forgings, and boiler-plate.

Cast Steel.—For the manufacture of cast steel, bars of blistered steel which are highly carbonized are broken into small pieces, melted in a crucible, cast in an iron mould, and form cast steel. The form of the pots or crucibles is long and narrow, and they usually contain 30 or 40 lbs. of metal. Pots are manufactured of fire-clay mixed with coke, or anthracite dust, or plumbago. An ordinary clay pot will last for one day, or three heats.

Where the steel-pots are made of fire-clay and upon the works, the pot-flask or mould, and plug, are commonly of the form Figs. 7035, 7036. The pot-mould is of cast iron, with two ears cast upon it to lift it by. Its inside is the shape of the outside of the pots; it is turned smooth, and is open at the bottom as well as at the top. There is a loose bottom made to fit, but not so small as to pass through; this has a hole in the centre ⅞ in. in diameter. When in use, it stands upon a low post firmly fixed in the ground, which has also a hole 5 or 6 in. deep in its centre. The plug which forms the inside of the pot is of lignum-vitæ; it has an iron centre, which projects through it about 5 in., corresponding in size with the hole at the bottom of the mould. The clay for each pot weighs about 24 lbs.; it is moulded upon a strong bench into a short cylinder, and the inside of the mould having been well oiled, the clay is dropped into it, and the plug, also oiled, forced into the clay, while the projection finds the hole in the loose bottom in the centre of the mould, which guides the plug. The plug is driven down 2 or 3 in. by the blows of a heavy mallet on the top of the iron head; it is then taken out, to be oiled again, by putting a piece of round iron through the hole in the iron head to lift by, giving it, at the same time, a screwing motion. It is then driven by the mallet, while the clay, rising up between the plug and the mould, reaches the top. The clay is cut even with the top of the mould with a knife, and the plug taken out; the pot is then narrowed at the top by passing the knife round between it and the flask or mould several times, holding it inclined towards its centre. The mould is now taken and set with its loose bottom upon a small post fixed in the floor, and the mould gently allowed

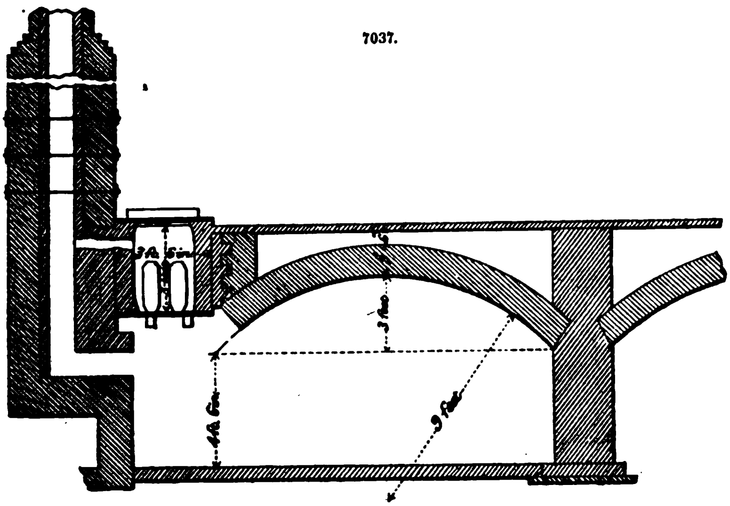


7034. 7035. 7036.

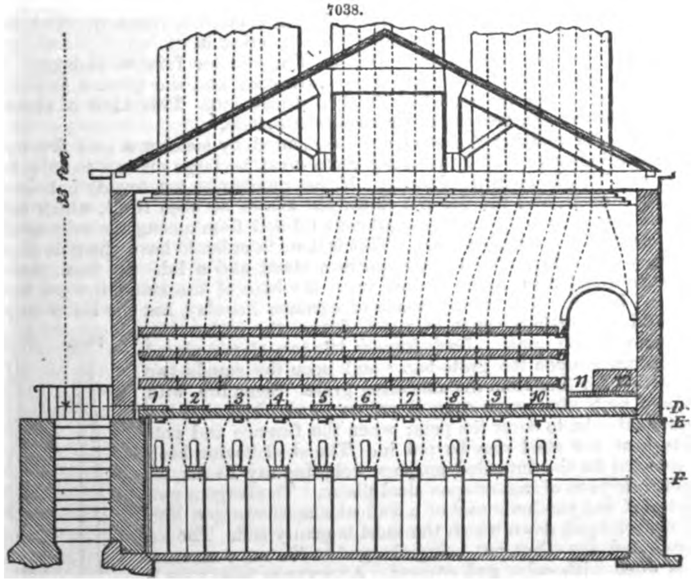
to rest upon it. This pushes up the bottom with the pot upon it; and the hole being filled with a bit of clay, the pot is finished. When the pots are sufficiently hard to bear handling, they are placed to dry upon rows of shelves, against the flues in the furnace.

The form of the melting furnace, and the direction of the fire and flue, will be understood from Figs 7037 to 7039. Fig. 7038 is a section of a ten-hole melting furnace, showing the direction of the

7037.



7038.



flues and the form of the holes when about half worn, with one row of the pots in their places; 1 to 10 are the flues of the melting holes, each one of which is carried up separately, and lined with fire-brick to the top; 11, an open fire-grate; 12, the annealing grate, closed in front by a cast-metal plate, rather broader than the depth of the melting pots; A, B, C, three broad bars of iron, bolted to others at the back of the flues by cross-bars, to tie the chimney-stack firmly together.

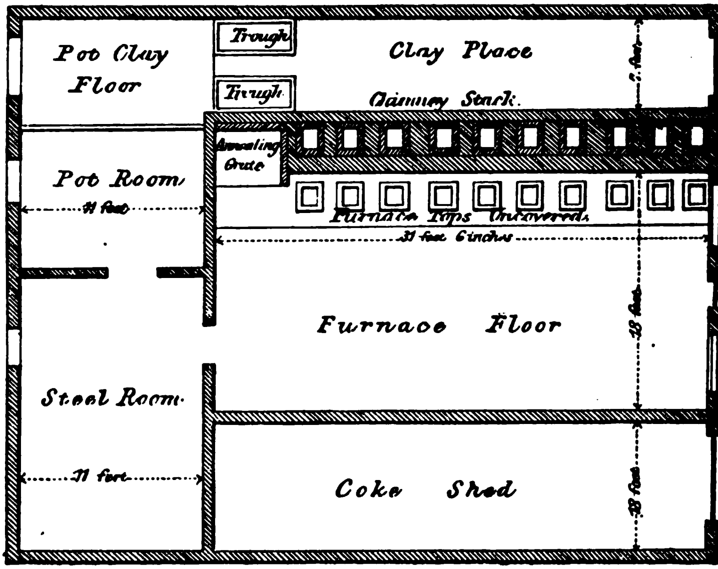
When the furnaces or holes become so wide as to waste the coke, the whole materials of the old melting holes—represented on the cross-section, Fig 7037, as occupying a space of 3 ft. 6 in., by 3 ft. 3 in.—are taken out, and new ones built of a kind of natural faced fire-stone like flags from 2 to 4 in. thick, cut into pieces 7 or 8 in. broad. These usually last four or five weeks before they want removing.

The cross-section, Fig. 7037, shows the position in which the two pots stand in the hole, and the cover in its usual position.

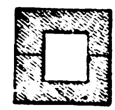
The cover-frame, Fig. 7040, is made of wrought iron 3 in. broad, by $\frac{3}{4}$ in. thick. A large fire-brick, made to fit, is held in its place by the movable bar of iron being pressed against it by

two screws. The handle is of round iron, about 16 in. long. The furnace tops, Fig. 7041, upon which the covers rest, are of cast iron, an inch thick, cast in two parts. The plan, Fig. 7039, is a

7039.



7040.



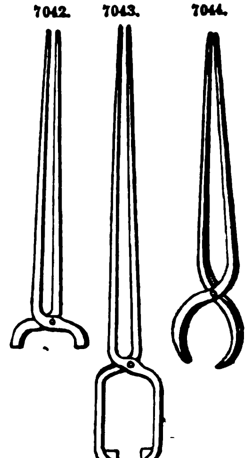
7041.

common arrangement of the other rooms connected with a melting furnace. The two troughs in the clay-place are for melting the clay previously to tempering it.

Instead of fire-stone, ganister is often used in England for furnace linings. In this case, wooden moulds are employed of the form of the furnaces; and the ground ganister, moistened with water, is put round the mould, which is then drawn out. This kind of stone is found in irregular masses, usually with fire-clay and carboniferous shale.

The preparations for melting the steel are commenced by making a coal fire upon the grate adjoining the annealing grate. The annealing grate must be large enough to hold twice as many pots as there are melting holes in the furnace. If that number be ten, twenty pots are put inverted upon the annealing grate, and the fire put down the spaces between them, which are then to be filled up, so as to cover the pot with the small coke riddled from among the coke used for melting, and upon these again the pot-lids are laid. This is done in order to have the pots gently heated to a red heat, ready for using. Each pot requires a stand and a lid. In form, the stand is the frustum of a cone about 3 in. high; and as upon the base of the stand the pot is to rest, they should correspond in size. The stand is made of common fire-clay, but the lid of clay the same as the pot; it should be a little larger in diameter, flat on the under side, and a little convex on the upper. Each furnace has two stands placed in the proper position upon the grate-bars; and upon the stands two pots, covered with their lids, from the annealing grate. Some fire, with a little coal, and soon after some coke, is put on; and when this has burnt up, sufficient coke to cover the pots; when the furnace and pots are at a white heat, the steel may be put in. The steel having been broken and selected for the intended purpose, weighing say 34 lbs. for each pot, is put into pans of iron or upon steel plates. To charge a pot, the lid is taken off, and the lower end of a conical-shaped charger, Fig. 7034, placed over the pot, down which the steel is gently slid. The lid is then replaced, and the other pot being charged in the same manner, the furnace is filled with coke, and covered. Afterwards more coke is added, the quantity being determined by the experience of the steel maker.

7042. 7043. 7044.



Four hours will finish the heat, when a man removes the crucible, by means of basket-tongs, from the fire, and puts it on the floor. Another workman takes the pot and pours the metal into the mould. Meanwhile the furnace is cleared of clinkers and made ready to receive the hot pot when emptied into the mould.

The ingots thus manufactured are drawn under hammers into the desired forms of bars. A brown-red heat only can be applied to this steel without breaking it; it requires, therefore, a great deal of heating and hammering. This steel cannot be fagoted, and is welded to iron with difficulty. It may be united with wrought iron in casting it on hot and clean iron, or welding it by means of fluxes, such as borax, or prussiate of potash.

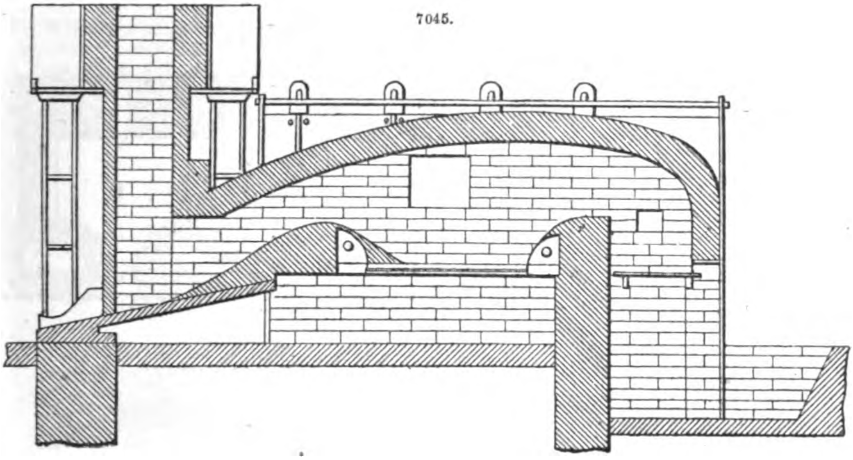
Before the steel is well melted, it appears to be in a state of ebullition; but when it is ready for pouring it has a clear surface, and rests in the pot without motion.

Figs. 7042 to 7044 are of several forms of tongs for lifting the pots for pouring.

Cast steel is largely manufactured, and for some purposes is preferred to all other kinds of steel, notwithstanding the larger quantities and cheaper rates at which these are produced.

A considerable quantity of a kind of natural steel is produced from pig iron by working it in a puddling furnace in a peculiar manner. Fig. 7045 is a section of a steel-puddling furnace.

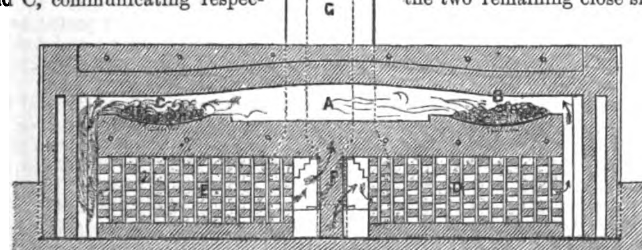
7045.



A charge of about 280 lbs. of pig iron is introduced into the furnace, and the temperature raised to redness. As soon as the metal begins to fuse and trickle down in a fluid state, the damper is partially closed, in order to temper the heat. From twelve to sixteen shovelfuls of iron cinder, from the rolls or squeezers, are added, and the whole is uniformly melted down. The mass is then to be puddled with the addition of a little black oxide of manganese, common salt, and dry clay, previously ground together. After this mixture has acted for some minutes, the damper is fully opened, when about 40 lbs. of pig iron are put into the furnace, near the fire-bridge, upon elevated beds of cinder prepared for that purpose. When this pig iron begins to trickle down, and the mass on the bottom of the surface begins to boil and throw out blue jets of flame, the pig iron is raked into the boiling mass, and the whole is then well mixed together. The mass soon begins to swell up, and the small grains begin to form in it and break through the melted cinder on the surface. As soon as the grains appear, the damper is three-quarters shut, and the process closely inspected while the mass is being puddled to and fro beneath the covering layer of cinder. During the whole of this process the heat should not be raised above cherry redness, or the welding heat of shear steel. The blue jets of flame gradually disappear, while the formation of grains continues; these grains very soon begin to fuse together, so that the mass becomes waxy and cherry red. If these precautions are not observed the mass will pass more or less into iron, and no uniform steel product can be obtained. As soon as the mass is finished so far, the fire is stirred to keep up the necessary heat for the succeeding operation, the damper is entirely shut and part of the mass is collected into a ball, the remainder being always kept covered with cinder slack. This ball is brought under the hammer and then worked into bars. The same process is continued until the whole is worked into bars. When pig iron made from sparry iron ore, or mixtures of it with other pig iron, is used, only 20 lbs. of the pig iron are added at the later period of the process, instead of about 40 lbs.

Siemens' Furnaces.—Fig. 7046 is a longitudinal section, Fig. 7047 a sectional plan, and Figs. 7048, 7049, transverse sections of a Siemens' furnace applicable to heating steel. The furnace consists of the heated chamber A, and of two fire-places or solid hearths B and C, communicating respectively with the two regenerators D and E. The valve F consists of a rectangular box of iron open at the two sides to the two regenerators D and E, at the bottom to the atmosphere, and at the top to the chimney G. A spindle passes through the centre of the two remaining close sides of the box,

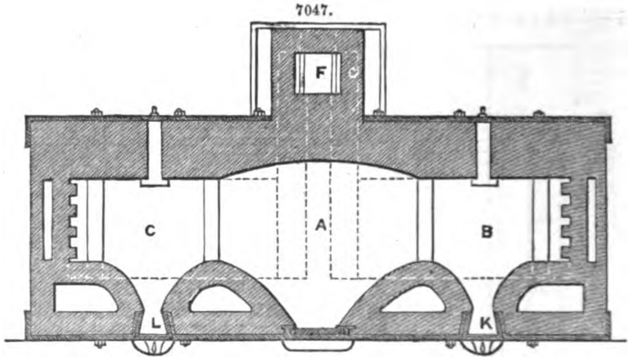
7046.



and carries a rectangular flap, fitting the box sideways, and bearing against one of its upper and one of its lower edges, according to the position of the tumbling lever and weight H, which are

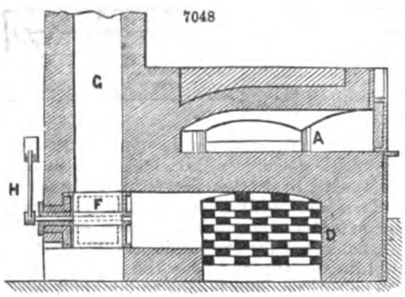
fixed upon the spindle outside. When the valve is in the position shown dotted in Fig. 7046, the atmospheric air entering from below proceeds in the direction indicated by the arrows, passing through the regulator D over the fire-place B, through the heated chamber A over the fire-place C, through the regenerator E and by the valve F, into the chimney G.

7047.

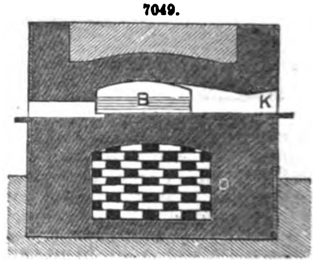


A fire having been lighted upon the hearth B, through the side opening K, the flame passes through the furnace and through the regenerator E to the chimney G, heating on its passage the perforated walls. After working an hour the valve F is reversed, fuel supplied through the opening L to the second fire-place C, which is then operated upon in an opposite direction to that indicated by the arrows. It is evident that by a continuation of the process an

7048



7049.



accumulation of heat to any degree may be produced within the furnace, provided only the heat produced in combustion is greater than the heat lost by radiation and the heat absorbed by the metal in the heating chamber. Modifications of Siemens' furnace are largely employed for making cast steel, and also in the production of steel by fusing pig iron with wrought iron upon the open hearth, known as the Siemens-Martin process.

See Crucible. Founding and Casting. Iron.

Works relating to the subject;—Mushet (D.), 'Papers on Iron and Steel,' royal 8vo, 1840. Percy (Dr. J.), 'Iron and Steel,' 8vo, 1864. Crookes and Röhrig's 'Metallurgy,' vol. iii., "Steel," 8vo, 1870. Grüner (M. L.), 'The Manufacture of Steel,' translated by Lenox Smith, 8vo, 1872. 'Journal of Iron and Steel,' 1871–73. Overman (F.), 'The Manufacture of Steel,' crown 8vo, Philadelphia, 1873. Dessoye (J. B.), 'Guide Pratique de l'Acier ses propriétés,' 12mo, Paris. Landrin (H. C.), 'Traité de l'Acier,' 12mo, Paris.

STEP. Fr., *Crassandine;* Ger., *Fusslager;* Ital., *Cuscinetto inferiore;* Span., *Rebajo.*

In machinery, a *step* is a kind of bearing in which the lower extremity of a spindle or a vertical shaft revolves.

STIRRUP. Fr., *Etrier;* Ger., *Springropp;* Ital., *Staffa;* Span., *Estribo.*

Any part of a machine resembling in shape or in functions the stirrup of a saddle, is called the *stirrup.*

STONE. Fr., *Pierre;* Ger., *Stein;* Ital., *Pietra;* Span., *Piedra.*

See Construction. Masonry.

STOVE. Fr., *Poêle;* Ger., *Ofen;* Ital., *Stufa;* Span., *Estufa.*

See Iron.

STRAP. Fr., *Lien;* Ger., *Band;* Ital., *Collare;* Span., *Abrazadera.*

A *strap* is a band or strip of metal, usually curved to clasp or hold other parts; as a beam-strap, a spring-strap; especially the U-shaped part of a strap-head which clasps and holds the brasses. The *strap-head* is a journal-box formed at the head of a connecting rod; see Fig. 2361, p. 1194.

STROKE. Fr., *Course;* Ger., *Hub;* Ital., *Corsa;* Span., *Arcera.*

The *stroke* is the entire movement of the piston of a steam-engine from one end to the other of the cylinder. The respective strokes are distinguished as *up* and *down* strokes, or *front* and *back* strokes, the front stroke being towards the cross-head. In the United States, the stroke of a locomotive piston towards the front of the engine is called the front stroke. The term is also applied to the movement of the cross-head and other parts moving with the piston. The movement of a slide-valve is called its *travel* or *throw.* The movement of a crank or an eccentric is called its throw.

SUGAR-MILL. Fr., *Moulin à sucre;* Ger., *Zuckermühle;* Ital., *Laminatojo da canne di zucchero;* Span., *Molino de azúcar.*

The machinery employed in the manufacture of sugar may be divided into that used for extracting the juice; for clarification, or separating the pure liquor from extraneous and deleterious substances; for evaporation, or driving off the water which holds the sugar in solution; and for

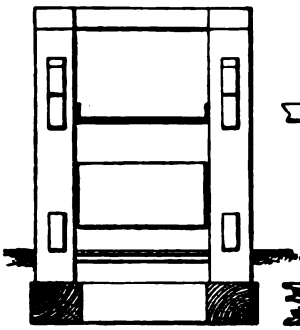
curing, which includes the processes of drying, and, when required, of bleaching the sugar obtained by evaporation.

The chief sources of sugar are the sugar-cane and beet-root. Of these the sugar-cane is the more important, and we shall therefore confine our remarks to the extraction of juice from the cane. The cane, when fully grown, ought to be about 8 ft. high, and 1½ in. diameter in the stem, with a top of 3 or 4 ft. above. The stem consists of a core full of sweet juice—in fact, nothing but sugar and water—surrounded by hard, woody fibre, which is again encased in a coating of silica, and it is these outer casings that occasion trouble in properly expressing the juice.

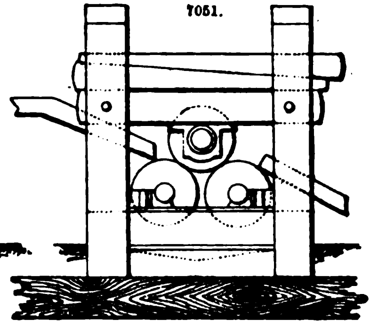
A common method of obtaining the juice, and one still used in rough countries, is to pass the cane between two vertical rollers of hard wood, set in a strong wooden framework and driven by cattle; the three-roller horizontal mill is, however, now almost universally employed in expressing cane-juice.

Before the use of iron became general, a simple system of framing, Figs. 7050, 7051, consisting

7050.



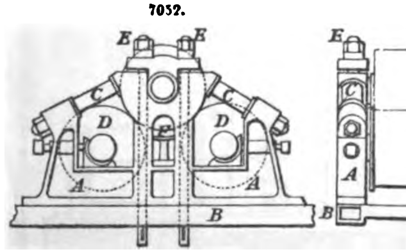
7051.



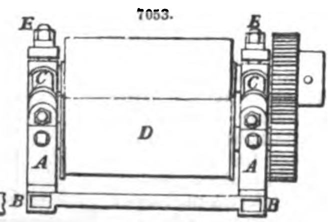
almost entirely of timber, was much adopted. The wood used is of the hardest description, generally obtained from the bullet, or bully, tree, which is somewhat similar but superior to teak. The framing is very massive, timber of about 16 in. square being used for a mill with rollers 4 ft. long by 2 ft. in diameter, and mortised and pinned together as firmly as possible. The only ironwork requisite consists of two light side-frames upon which the metal bearings are fitted, and which also carry the dumb returner. The advantages of this description of framing are;—That it can be made in the country; that the cast-iron portion has very little strain upon it, and therefore is not liable to break; it is economical, as good timber can usually be obtained at a moderate distance, and although skilled labour is dear, the expense of carriage is saved, and it can be repaired easily, which we consider the chief recommendation for wood framings. When properly constructed, the weakest portion consists of the two wedges above the bearings of the top roller, so that in case of any hard substance being passed between the rollers, the only damage done would be the straining, and perhaps breaking, this portion of the mill. For this reason it is customary to keep spare wedges in stock, so that they may be renewed in a few minutes if a breakage occurs. These wedges are also useful on account of their elasticity permitting a certain amount of play between the top and the two bottom rollers, by which means they adjust themselves to variations in the feed.

The most usual description of sugar-mill is shown in Figs. 7052, 7053; Fig. 7053 being the front, and Fig. 7052 the side elevation respectively. In this case the rollers are similar to those of

7052.



7053.



the wooden-framed mill, but are of cast iron fitted with wrought-iron gudgeons, the distance between the roller and the bearings being less than an inch. The framing is of cast iron, each side frame being cast in one piece.

A, A, are the side frames fitted on the bed-plate B. C, C, bolts fitted with distance-pieces and firmly screwed up so as to strengthen the framing in the direction of the thrust between the top and the two bottom rollers. The reason bolts are employed, instead of casting that portion of the framing solid, is to remove the bottom rollers in case of necessity. The lower rollers D, D, are provided with flanges for preventing the cane from getting out at the sides, and are adjusted by means of screws. Another method has been applied, of acting simultaneously upon each pair of screws by means of a horizontal shaft and bevel-gearing attached to their heads, somewhat similar to the adjusting gear of an iron mill, as in Fig. 4472. The bolts that hold down the top roller are carried through the framing and secured by a cotter at the lower end. In some mills they

are only carried down a short distance, the cotter being passed through a slot in the framing, but this plan throws all the upward strain on the cast-iron framing, which, if broken, could not be repaired with the same facility as the bolts. The dumb turner, or dumb returner, F, Fig. 7052, is a curved plate of iron, usually perforated and grooved, so placed as to receive the canes from the front roller and guide them on to the back roller. For clearness of illustration the feeding table and delivery are omitted, but are shown in Fig. 7051. They consist simply of a flat surface and two sloping surfaces, to allow the canes to slide down them, the portion of the delivery nearest the roller being fined off to a knife-edge and set as close as possible to it, to prevent the crushed cane from being carried round in consequence of its sticking to the surface.

7054.

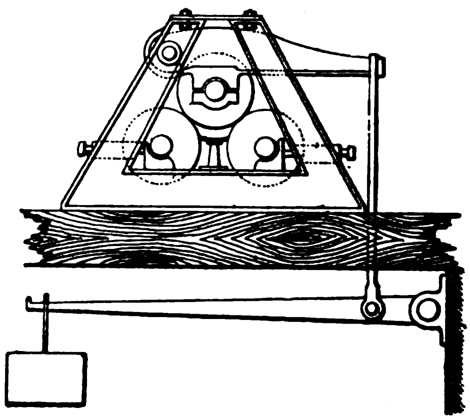


Fig. 7054 is a side elevation of a mill designed to obviate the excessive strains to which sugar-mills are constantly and almost suddenly subjected. It will be seen that in this arrangement the top roller is kept down by a compound lever, and as the distance of the weight from the fulcrum of the lower lever or the weight itself can easily be varied, any required pressure may be obtained. As it is not at all unusual for the feed to vary so much that at one moment few if any canes are passing between the rollers, whilst at the next the mill is choked with them, the play here permitted becomes of the highest importance.

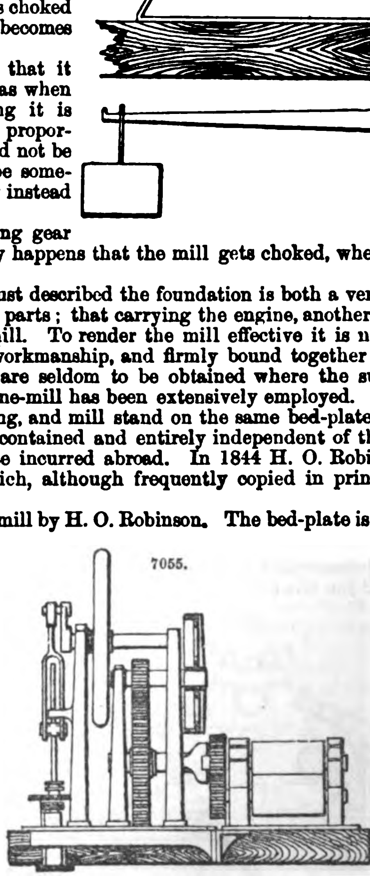
The disadvantage of this mill is that it allows too great an amount of play; as when a large quantity of canes are passing it is necessary that the pressure should be proportionately great, or the inside ones would not be properly crushed. This fault might be somewhat overcome by the use of a spring instead of a weight.

Although not often applied, reversing gear is very essential, as it not unfrequently happens that the mill gets choked, when it is necessary to reverse in order to free the rollers.

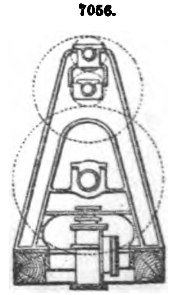
Combined Cane-mills.—In the mills just described the foundation is both a very important and a very costly item. It consists of three parts; that carrying the engine, another carrying the intermediate gearing, and that under the mill. To render the mill effective it is necessary that these should be very massive, of first-class workmanship, and firmly bound together by iron or timber. As good materials and workmanship are seldom to be obtained where the sugar-cane grows, a species of mill called the combined cane-mill has been extensively employed. This term includes all those mills where the engine, gearing, and mill stand on the same bed-plate, so that the strain upon the various parts should be self-contained and entirely independent of the foundations, and thereby do away with the chief expense incurred abroad. In 1844 H. O. Robinson introduced an arrangement for a combined mill, which, although frequently copied in principle, did not as a whole come into general use.

Figs. 7055, 7056, are of a combined mill by H. O. Robinson. The bed-plate is made in two pieces, and, as in this case, is adapted for altering an old mill into a combined mill by the attachment of the old bed-plate of the mill to the bed-plate of the engine by means of strong brackets. In a new mill, however, the bed-plate would be cast in halves and bolted together. In order to reduce the number of revolutions of the engine-shaft to that requisite for the mill-rollers, double gearing is employed, the first pair of wheels being internal. By this arrangement the spur-gear is brought within convenient proportions, and the only defect is the height of the crank-shaft from the bed-plate, which renders it rather unstable when the feed is moderately heavy.

7055.



7056.

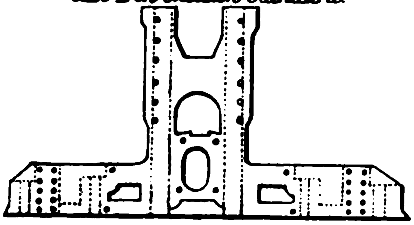


G. Buchanan constructs the side frames of sugar-mills with a combination of cast and wrought iron, by which means a degree of lightness and strength is attained far superior to that of any iron mill we have described. The cast-iron skeleton side frame is made as in Fig. 7057; upon each side of this is fitted a stout wrought-iron plate about an inch thick, and cut out as in Fig. 7058 to the requisite pattern to form the frame. The wrought-iron sides and cast-iron skeleton are firmly fixed together by riveting through holes made to correspond, Figs. 7057, 7058. To avoid the necessity of supplying two spare rollers in case of accident, that is, one for the top and one for the bottom, the flanges of the bottom rollers are dispensed with, so that all three rollers being alike, only one spare one is required. The canes are prevented from getting out at the ends of the rollers by means of a fender-plate A, Fig. 7059, fixed at each end of the top roller, which fits in between the feed and delivery tables B, C. To avoid lifting the bottom rollers when they are required to be taken out,

the openings in the side frame are made horizontal; by this means also the top roller need not be removed before drawing out the others. Wrought-iron tie-bars, shown in dotted lines at D,

7057.

Cast Iron Skeleton Standard.



7058.

Cast Iron Skeleton for each side of Standard.

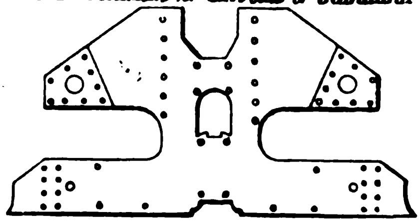


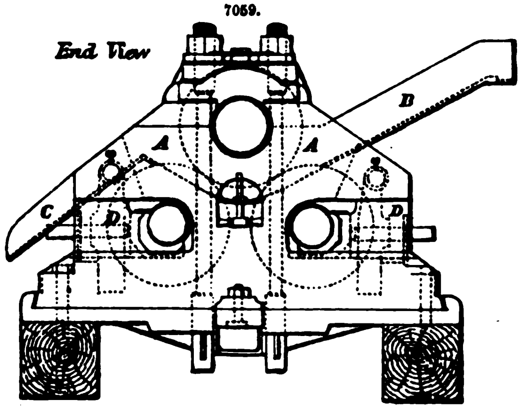
Fig. 7059, are used for the purpose of bracing together the framing, and also for setting up the lower rollers, these bars being topped to receive the adjusting screws.

Fig. 7060 is an elevation of one of these mills complete. In this case it will be seen that the machinery is kept well down, so that great steadiness is obtained. As in Figs. 7055, 7056, double gearing is employed, only the internal spur-gearing is used for the second motion instead of the first, thus placing the strongest form where the greatest strain occurs.

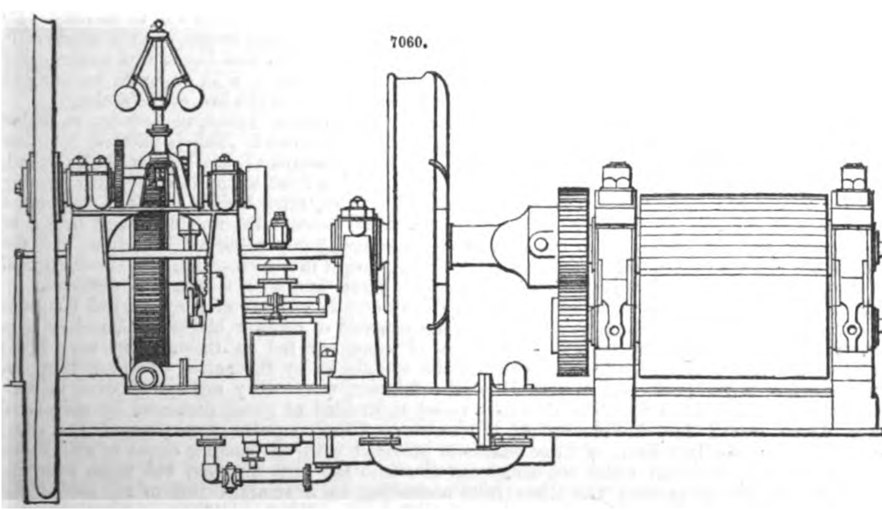
For convenience in feeding cane-mills a cane-carrier is sometimes used. This consists in an endless band, the width equal to the length of the rollers and of any desired length. It is usually made of thin slots of wood attached to a pitch chain running over wheels in the usual

7059.

End View



7060.



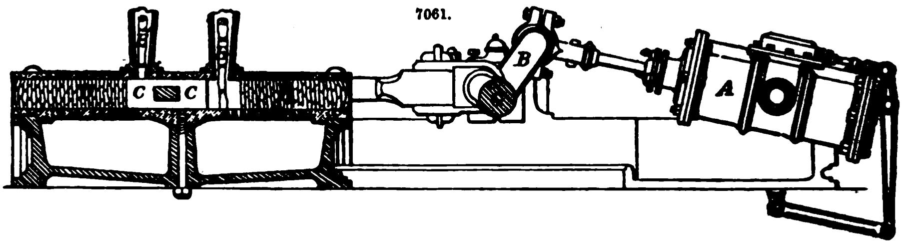
manner. The driving wheel is generally connected, either by a belt or gearing, to one of the mill-spindles. By this means the canes can be spread evenly over the table and fed into the mill with much greater regularity than the old method of pitching the bundles of cane directly between the rollers. A trash elevator, made in a similar manner, is also used for carrying away the crushed cane or trash into the drying sheds.

Besides roller mills two or three other methods of extracting the juice from canes have been tried.

Henry Bessemer, in 1849, devised an arrangement, a side elevation of which is given in Fig. 7061. It will be seen that it consists of an engine A driving a crank-shaft B, upon which there are two cranks working the plungers C. These plungers work backwards and forwards in two rectangular boxes D, the sides and bottom of which are pierced with small holes, while the ends are open. These boxes were intended to be parallel throughout, but afterwards they

were slightly contracted towards the ends. In the figure, only one box and plunger can be seen, the other being arranged alongside. To work this press a cane is put into each of the

7061.



four hoppers E, E′, and the engine started; when, as the plunger moves to the end of its stroke, Fig. 7061, it leaves the bottom of the hoppers E open, and allows the canes to drop down into the boxes D. Upon the return stroke the plunger cuts off those parts of the cane that are in the box and forces them along the rectangular casing, and while thus acting it leaves the openings of the hoppers E open, when the canes drop down into the box, and a similar process is repeated on the return stroke of the plunger. By this means the rectangular chambers become filled with pieces of cane equal in length to the height of the box. It was thought that as the canes were somewhat roughly cut off they would offer considerable resistance to the plunger as they were gradually forced to the open ends of the boxes, which resistance would be increased in proportion to the number of pieces of cane; and that when the boxes were full their united resistance would be so great that the pressure required to force them along would completely press out the juice through the perforations B′ in the box. When the machine was tested in England with canes brought, we believe, from Madeira, this result was fairly obtained, but in this case the canes were very hard and tough. When tried afterwards in the West Indies with fresh juicy canes it was found impossible to obtain sufficient pressure, and with parallel chambers the pieces of cane were shot out at the open end as fast as they were cut off. When the chambers were tapered so as to prevent this, the shock at each stroke of the plunger became so excessive as to endanger the machinery, whilst very little juice was expressed.

Another method of extracting the juice, used both for canes and beet-root, is that known as the diffusion process. In 1844 Constable proposed to cut the cane into cross slices by means of a revolving shaft carrying a number of circular cutters on it, and so placed that the slices were made about the tenth of an inch thick. These slices of cane were then to be put into vessels and cooked in hot water until the sugar was dissolved out. A series of vessels was to be employed, so that as the liquor in the first became too much charged with sugar to dissolve the whole of it out of the contained slices, they were placed in the next, wherein the liquor was weaker, and so on until the liquor in the first vessel became sufficiently charged with sugar to be pumped out into the evaporating pan, when this first vessel in its turn became the last of the series.

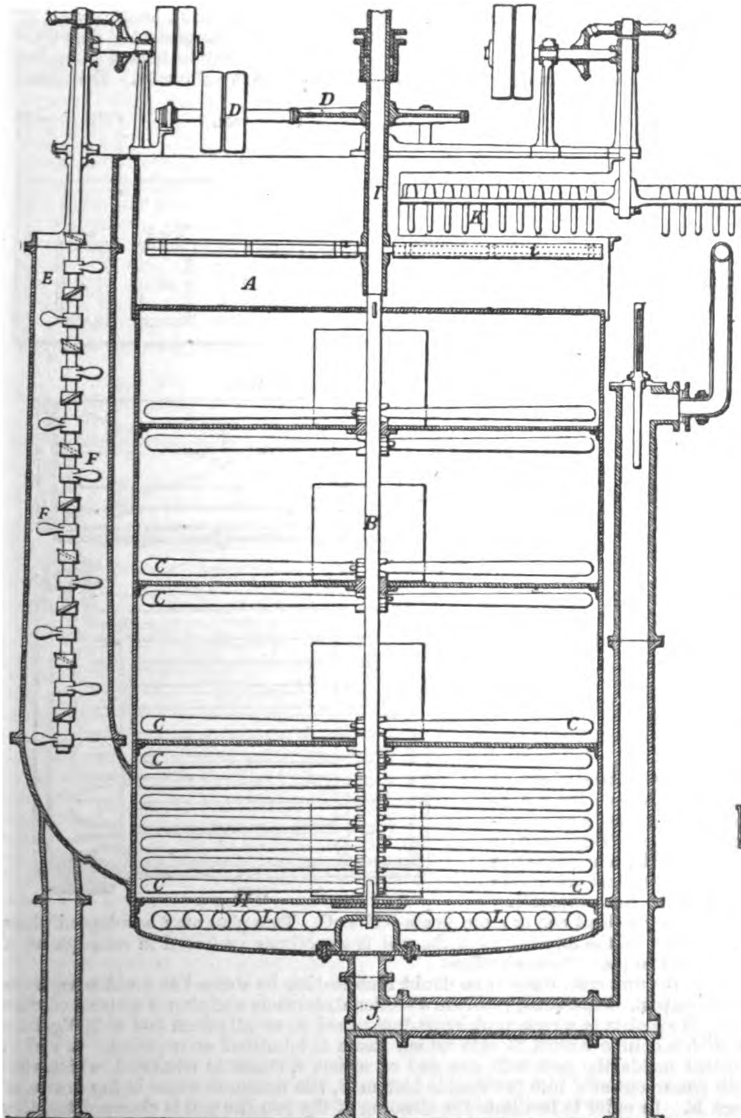
An improvement upon this method was made in 1869 by Julius Robert, of Austria, in which the entire process of diffusion is carried on continuously in one vessel. This is effected by introducing the slices of cane or beet-root through a feeding apparatus at the bottom of the vessel, from which they rise slowly and gradually to the top, while the fresh water is constantly running in at the top, and is drawn off at the bottom as diffusion juice, after having remained in contact with the slices a sufficient time. The water in its gradual descent through the entire height of the diffusion vessel passes through all the stages of gradually increasing concentration, and the sugar in the slices, in their ascent, becomes gradually extracted in a corresponding manner, so that the whole process of extraction is carried out in a single vessel instead of a battery of diffusers.

Fig. 7062 is a sectional elevation of Robert's diffuser. It consists of a cylindrical diffusion vessel A fitted with a central shaft B which carries a series of arms or blades C, C, and is kept in slow rotation by the gearing D. The slices of cane are fed in through the tube E by means of a series of screw-blades revolving on the spindle F, by the action of which they are forced down into the perforated bottom H of the diffuser, where they are spread over its surface by the rotating arms C. The diffusion vessel is divided at equal distances by perforated plates, which permit the free descent of the water or diffusion juice, but prevent the slices from rising too rapidly. Each of these plates is provided with an opening equal to about one-eighth of its area, through which the slices can rise into the next division, but these openings are so placed as to prevent the slices from ascending in a straight line to the top of the vessel. Each perforated plate has a revolving blade C above and below. The water is introduced at the top of the vessel through the perforated pipes *i*, *i*, connected with the main pipe I. The diffusion juice is drawn off through the pipe J, and the extracted cane is swept off by the revolving scraper K. A coil pipe L is provided for heating the juice by steam if required.

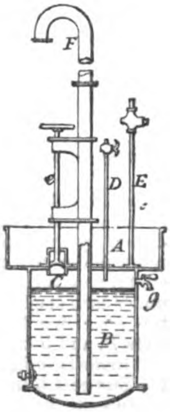
The cane-juice in its way from the mill to the clarifiers passes through a strainer for the purpose of freeing it from bits of cane and other mechanical impurities. This strainer consists of a series of three or four perforated plates, the holes in the lowest being the smallest. The top plate, which stops all the large pieces, is frequently roughly cleared out by hand, and when the mill stops the whole are properly cleaned. As the clarifiers are usually placed considerably higher than the mill the juice has then to be raised. This is generally done by means of large-barrelled, short-stroke pumps, worked from one or more of the roller gudgeons; usually two pumps are employed, to prevent stoppages in case of one getting choked. The objections to the use of pumps are, that a certain amount of grease and metal from the working parts is mixed with the juice, and also that the juice

is kept too long at a temperature most suitable for fermentation. A French invention, termed a monte-jus, Fig. 7063, is now very generally substituted for these pumps. The body of the monte-

7062.



7063.

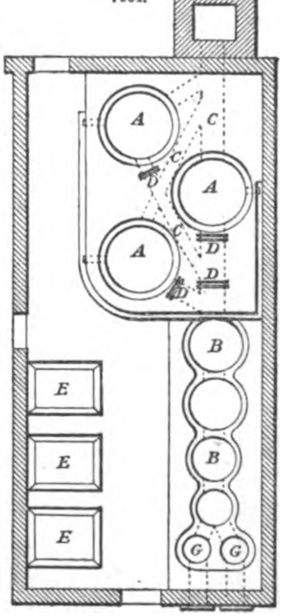


jus consists of two parts, A and B, separated by a steam-tight diaphragm; the upper part A receiving the juice from the mill, while the charge in the lower portion is elevated. When the lower part B is empty the valve C is raised by means of the handle c, and at the same time the cock of the air-pipe D is opened. The juice in the upper portion A at once descends into the chamber B, the valve C being left open until it is sufficiently full, and then screwed down. In order to ascertain when the chamber B is charged, the air-pipe D is carried down from 4 to 6 in. below the top of the chamber B, or to the height to which the juice should attain; the cessation of the whistling noise made by the air rushing out at this air-pipe being the signal for shutting off the supply. The air-cock being closed, steam is introduced through the steam-pipe E, when the pressure on the surface of the juice forces it out through the discharge-pipe F. As this pipe is carried down to within a short distance of the bottom, the whole of the liquor is discharged from the lower chamber. A small cock g is provided in case the chamber B should be allowed to get too full, as in that case the steam, when let in through the pipe E, mixes with the juice and condenses. By this method of raising the juice it is kept free from grease and dirt, there being no working parts in the machine; it is also made sufficiently warm to retard fermentation.

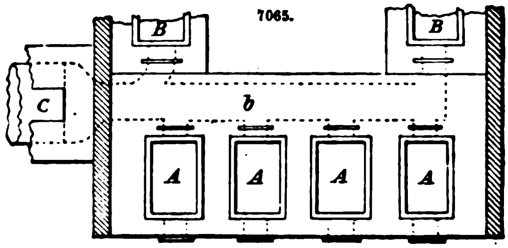
Clarification.—This process consists in removing, as far as possible, all impurities from the juice,

whether mechanical or chemical; we shall, however, confine ourselves to describing the clarifiers used in the almost universal practice of clarifying or defecating by common lime. These consist of two classes, clarifiers heated by an open fire or the waste heat from the evaporating pans, and those which are heated by steam. A very usual plan of heating by means of the waste heat from the evaporating pans is shown in Fig. 7064. Here the clarifiers A are circular pans, holding about 500 gallons each, and are heated by the waste heat from the battery B; the arrangement of flues C and dampers D illustrating the method by which any one or more clarifiers may be heated as required, and also the means by which the heat may be allowed to pass direct to the chimney. This plan is

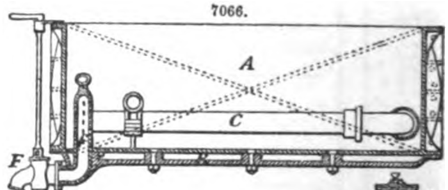
7064.

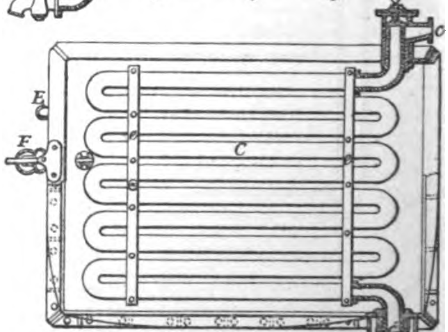


7065.



7066.





7067.

especially adapted to sugar-houses where no steam is used, where, for instance, the mill is driven by water power, and the juice evaporated under the old system. Fig. 7065 is another method of heating by a separate fire under each clarifier, the waste heat going into the same flue b as that of the evaporating pans B, and both combining to heat one or more steam-boilers C. This plan may be adopted where the sugar is finished in any of the modern methods, and is sometimes preferred in consequence of the first cost being much less than steam clarifiers.

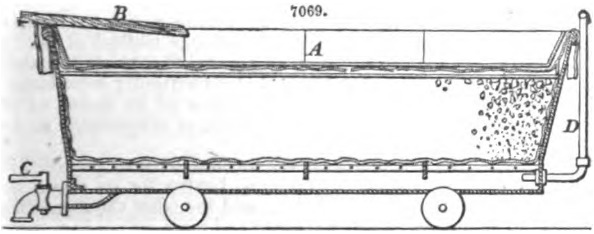
In spite, however, of the first cost, there is no doubt that heating by steam has great advantages and is eventually the cheapest. Figs. 7066, 7067, are a sectional elevation and plan of a steam clarifier of the ordinary type. It consists of a rectangular cast-iron vessel A, usually from 500 to 700 gallons in capacity, fitted with a double bottom B, into which steam is admitted as required. A coil of copper pipes C is fitted inside the pan, into one end of which, c, steam is admitted, which after traversing its length passes out at c' into the double bottom B, the condense water being drawn off by means of the cock E. In order to facilitate the cleaning of the pan the coil is clamped together at e e', and is fitted at c c' with stuffing boxes, so that by means of a ring-bolt fitted in the clamp e it may be lifted into an upright position. By this means it is evident that the liquor contained in the clarifier may be heated as soon as it is a few inches deep, and, what is of great importance, the steam can be shut off at the exact time required. The cock F, which is for the purpose of drawing off the liquor, is fitted with a plug f perforated with holes, placed at a suitable distance above the bottom of the clarifier, in order that the sediment formed during the process of defecation may be prevented from passing off with the clear liquor.

As soon as sufficient cane-juice has been run in, that is, as soon as it reaches to the top of the flues in the fire-heated pans or covers the coil in the steam pans, heat is applied. When the juice has attained a temperature of about 140° a small quantity of fine-ground lime, about 1 lb. to every 600 gallons of juice, is made into a milk, thrown into the pan and thoroughly stirred in. The temperature is then allowed to rise until the thick scum which forms at the top begins to harden and crack, when the heat is shut off, and the liquor, now clarified, allowed to stand for at least a quarter of an hour. In drawing off the liquor a small quantity of a dirty colour comes away first, which is usually returned into another clarifier while it is being filled. The liquor is then run into the filter or evaporating pans, as the case may be, until within a few inches of the bottom, about the height of the lower perforations in the plug, Fig. 7066, when upon it changing colour it is stopped.

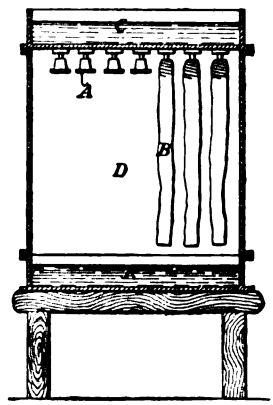
What is left, consisting of the top scum and bottom sediment, is usually sent to the still-house. In some places, however, where labour is cheap and the rum inferior, a scum press is used for extracting the contained liquor, which is either re-clarified or filtered. This press consists of a square chamber perforated with small holes, and into which a piston is fitted and worked down by a screw.

Filtration.—After clarification, or at a somewhat later stage of the manufacture, it is usual to filter the liquor, partly in order to get rid of the feculencies too minute for elimination by the former process, and also to decolorize and chemically purify it. In Fig. 7068 is shown what is called a bag or bell filter, the latter term being applied in consequence of the shape of the metal pieces, or bells A, to which the upper end of the bags B are attached. This filter consists of a casing, usually about 9 ft. high, 5 ft. wide, and 3 ft. deep. The upper portion C is a cistern, the bottom of which is pierced with a series of holes into which the gun-metal bells A are fitted. The bags B which are tied on to these bells, consist of an outer casing of coarse canvas about 8 in. in diameter and 6 ft. long, and inside this casing is stuffed a bag of twilled cotton, made expressly for the purpose, about 3 ft. in diameter, and the same length as the outer casing. The reason for making the inner bag so much larger than the outer, is to give more filtering surface, the outer casing being only of use to keep the other within bounds. The centre portion of the casing D is provided with doors the whole of its height and width for convenience in changing the bags as they become dirty. The lower portion of the casing E is a cistern for holding the filtered liquor which is drawn off as required. These filters have been found useful for cleaning the liquor, but they do not affect it in any other respect; besides which their height makes them inconvenient, and necessitates pumping.

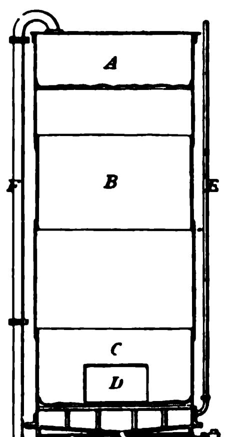
7069.



7068.



A charcoal filter to be used at this stage of manufacture is shown in Fig. 7069, where from its comparative shallowness the liquor may be run in without pumping. This consists of a light galvanized iron pan A running on a tramway. A perforated plate covered with a blanket is fitted about 6 in. from the bottom, and a similar division is made the same distance from the top. The space between these is filled with animal charcoal. The liquor from the clarifiers runs in through the gutter B, thence through the charcoal into the bottom compartment, whence it is drawn off by the cock C. A small pipe D is provided so that the liquor in passing through the charcoal should not be retarded by the air getting compressed in the lower chamber. The object of this filter is not only to remove the impurities similarly to the bag filter, but to partially discolorize the liquor and also to neutralize any acid that may remain.



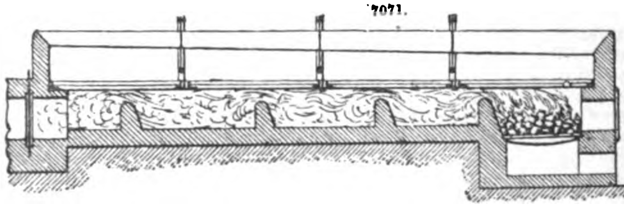
7070.

The general form of charcoal filter employed for making high-class sugar, principally in refineries, is shown in Fig. 7070. The filter is an upright cylindrical casing of wrought iron, divided into three compartments A, B, C, the top being a cistern for receiving the liquor, the centre and largest compartment containing animal charcoal, and the bottom being a small chamber fitted with a cock for drawing off the filtered liquor. A man-hole D is provided for cleaning out the exhausted charcoal, and an air-pipe E for letting off the air when the hot liquor is first run into fresh charcoal. The divisions between the compartments are formed of perforated plates upon which a coarse piece of woollen is placed, the upper division being used for distributing the liquor over the charcoal, and the lower for preventing the charcoal from coming through with the liquor. The liquor is elevated by a monte-jus through the pipe F.

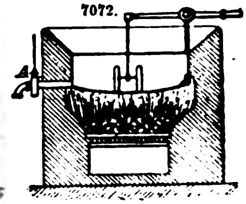
Evaporation.—There are two plans adopted for driving off the water in the liquor, which ought to be only sugar and water, as it comes from the filters, either by a naked fire from first to last, or partly by fire and partly by steam. The former, which is the old and perhaps still the most usual method, is illustrated in Fig. 7064, and consists of four coppers B, and two teaches C, under each of which is a furnace. The liquor is first run into the largest or grand copper, and as it evaporates is ladled into the next, and so on, until it arrives at the teaches almost sufficiently concentrated. In these it is still further evaporated until the liquor contains about 70 per cent. of crystallizable sugar, when it is skipped or struck, that is, emptied out into coolers E. In order, however, to evaporate even thus far, the heat is so great (242°) that the colour of the sugar is excessively darkened, and consequently its value greatly reduced. The only advantages this system possesses is that the plant costs but little, and also that skilled labour is unnecessary.

The modern method of evaporation consists in concentrating the liquor up to a point at which it is not likely to have its colour affected by the old method of an open fire, and afterwards bringing it up to the required state of concentration at a comparatively low temperature. The first portion of this process is similar to the old method without the teaches; but instead of having a series of coppers, a long rectangular boiler, divided into compartments, usually called a battery, is generally adopted. Figs. 7071, 7072, are longitudinal and cross sections of a battery. It consists of a long

7071.



7072.

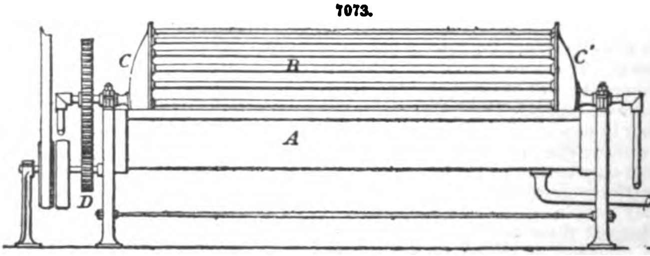


and somewhat shallow vessel, usually from 30 to 40 ft. long, 4 ft. wide, and varying in depth from about 26 to 30 in. at the end farthest from the fire to about 20 in. at the near end. It is set with bridges in the flues to prevent the heat going too much up the chimney, the brickwork being carried up 8 or 12 in. above the top of the pan, and bevelled off to allow space for the froth of the boiling liquor. The battery is divided into compartments by transverse partitions having sluice-valves at the bottom; these valves being worked by a lever, Fig. 7072. By this means the liquor is allowed to flow down, as required, without having recourse to the laborious method of ladling from one compartment to another. When the cane-juice has been evaporated to a density of about 29° Beaumé, at which degree the boiling point is about 224° Fahr., and consequently considerably below the temperature at which the juice is injured in colour, it is drawn off by means of the cock A, for the purpose of being treated by one of the following methods of evaporation at low temperature.

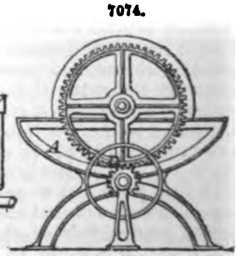
Methods for Concentrating Cane-juice at Low Temperatures.—Of the various schemes proposed for this purpose, two only have been found to be practically useful; one having for its object the exposure of thin films of heated liquor to the cooling effect of the air, and the other the rarefaction of the air in which the liquor is placed. The former, as being cheaper and more simple to manage, is generally used in modern sugar-houses of moderate dimensions; while the latter, evaporation in vacuo, is preferred on some large estates, and universally in refineries.

The Wetzel Concentration Pan, illustrated in Figs. 7073, 7074, consists of a semi-cylindrical pan A,

7073.



7074.



enclosed in a steam-jacket supplied from the exhaust of the engine, into which is fitted a cylinder of tubes B, fitted into the hemispherical ends C, C′. The liquor to be evaporated is run into the vessel A, and when full steam is admitted into the end C, thence through the tubes B, and out at the end C′, while at the same time the whole is caused to revolve slowly by means of the gearing D. By this means a film—the liquor, which is kept hot by the steam-jacket of the pan—is carried up into the air, and the moisture evaporated from it; the heat thus extracted being constantly supplied by the steam inside the tubes. As the steam used for this purpose is only of a moderate pressure the heat thus supplied is not sufficient to discolour the sugar. In fact, the amount of evaporation is so great that the temperature rarely exceeds 200°, and is usually much less. The only objection to this design of pan is that the tubes are apt to churn the liquor, and cause an inconvenient amount of froth, unless driven at an exceedingly slow speed. This defect has, however, been partially overcome by reducing the diameter of the drum, and giving it a proportionately greater length.

Another pan for accomplishing the same object, invented by Shroeder, is shown in Fig. 7075, where the drum of steam-pipes is replaced by a series of thin galvanized iron discs. This design has the advantage of not frothing or churning the liquor, and it is also much cheaper; but the process of evaporation is much slower, in consequence of the revolving portion being deprived of supplementary heat.

7075.

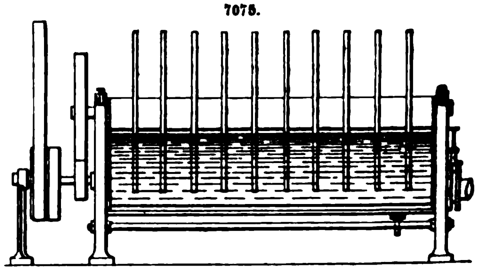
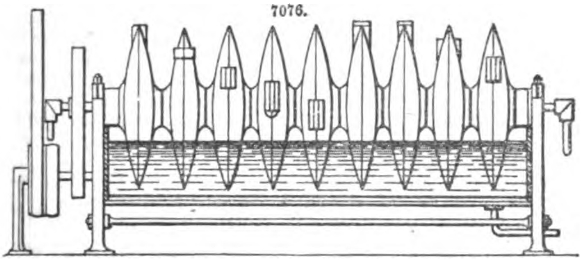


Fig. 7076 is a modification of this plan proposed by Bour, of Mauritius. Here the discs are made hollow and somewhat spherical, and are provided with cups after the principle of a dredging machine, the liquor scooped up by them being discharged over the surfaces of discs as they attain their highest elevation. In this case sufficient heat is obtained for rapid evaporation, and if the cups were removed no churning action could take place.



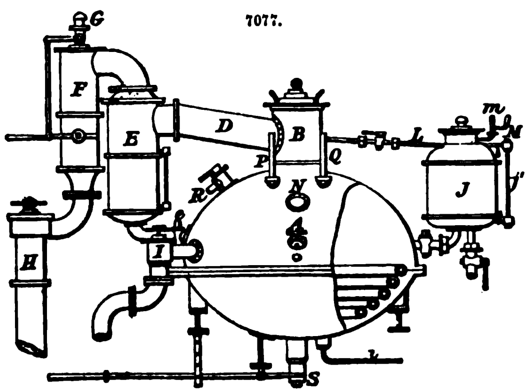
7076.

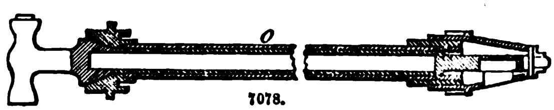
In working a pan upon one of the above principles the liquor is generally run out of the open-fire battery, as already described, at a density of about 27° Beaumé, directly into it until the liquor is within a few inches of the top. The discs or pipes, as the case may be, are then caused to revolve very slowly, and steam heat applied until a strong grain appears in the liquor, which is quite thick. It is then run out into coolers, when the pan is ready for another charge. Some sugar makers prefer to add fresh liquor to pan from time to time as it evaporates down, so that the pan is kept nearly full. The reason for this is that the crystals originally formed from the first charge act as a nucleus for those of the successive charges, and that consequently a bolder, or larger, grain is obtained. We think, however, that this object is better obtained in the coolers by making them sufficiently large to hold several skips, or else by dividing the skips among several coolers, as the temperature in the pans is generally too high for that purpose. The coolers are usually shallow, rectangular vessels made of hard wood, and having their sides sloping outwards as shown at E, Fig. 7064, a usual size being 6 ft. by 4 ft. by from 12 to 15 in. in depth.

The Vacuum Pan.—The best method of evaporating the liquor is by means of a vacuum, but unfortunately the machinery required for this purpose is not only very expensive, but it is also necessary to employ skilled labour to manage it.

The vacuum pan was invented by E. C. Howard in 1812, since which time various improvements in the details and many modifications in its shape have been made, but the principle has remained substantially the same. In Fig. 7077 is shown one of the best modern arrangements. The vacuum pan A is usually made of copper, the lower half being enclosed in a cast-iron jacket. A man-hole B is placed on the top for the purposes of cleaning and repairing. The pipe D is for the purpose of carrying off the vapour, and is fitted with a vessel variously termed a safe or tell-tale E, for catching the liquor if it primes over, when it is returned through the cock *e*, the amount of overflow being shown by the glass gauge attached to the side. The vapour passes on to the condenser F, the pipe G supplying the cold-water jet, and the pipe H leading to the air-pumps. The steam is supplied to the pan by the stop-valve I, and the condensed water is removed through the pipe *i*. A measure J, holding the right quantity of liquor to constitute a charge for the pan, is connected to it through a pipe, and is also provided with a glass gauge *j*. This measure is filled through a pipe leading to the liquor cistern, a vacuum being formed in the measure by means of the air-pipe L, connecting it to the top of the vacuum pan. A glass sight-hole N is fitted in the upper part of the pan, a similar sight-hole being placed on the opposite side, so that by looking through the one, the other, especially when assisted by a lamp, affords sufficient light to judge of the state of the contained liquor. In addition to this, means are adopted for extracting a sample from the inside of the pan without disturbing the vacuum, by the use of a proof-stick O, Fig. 7078, which is capable of being inserted and screwed air-tight into the pan in an oblique direction. This consists of a gun-metal rod with a cavity at the lower end for receiving the sample, and fitting into a hollow casing. At the lower end of this casing is fitted a shell-cock, the end of the gun-metal rod with the cavity being made square, fitting into the hollow plug and acting as a spanner. As the aperture of the plug corresponds to the cavity in the proof-stick, as soon as it is opened to the liquor a portion flows in, when by turning the plug half round connection with the contents of the pan is cut off, and the portion that has flowed into the cavity of the proof-stick can be safely withdrawn for examination. The pan, Fig. 7077, is also supplied with a thermometer P, and barometer Q, fitted to its upper half, for ascertaining the temperature and quality of vacuum inside. There is also a steam-pipe R, for cleansing the pan when necessary. When the syrup is sufficiently boiled it is discharged through the valve

7077.



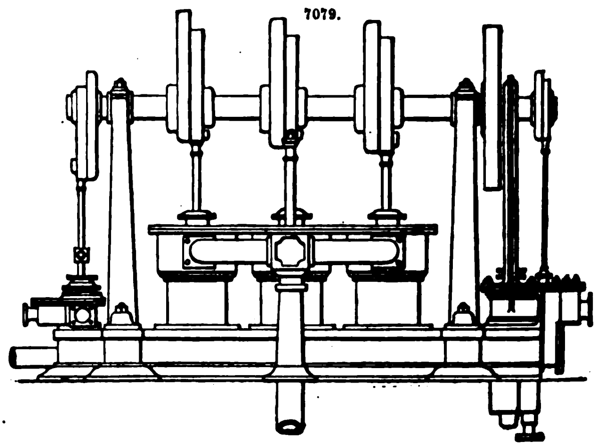


7078.

S, either into a cooler, a heater, or taken directly to the centrifugals. The most usual plan on sugar estates is to treat it in the old method, that is, to run it into coolers; but for making refined or white loaf-sugar it is discharged into a pan similar to the bottom half of the vacuum pan, but without the coil, where it is raised to a temperature of 180° to 200° before being run into the moulds. Some prefer to pass it through the centrifugals at once, as it is cured much more quickly; but this is only in consequence of the large proportion of sugar held in solution, and which would have crystallized if left to cool. As but few estates are large enough to keep a vacuum pan constantly going, it is usual to run the half-concentrated liquor into tanks or subsiders, in order that what impurities are left may be allowed to separate before the liquor is drawn up into the pan.

Fig. 7079 is an elevation of a set of vacuum pumps.

7079.



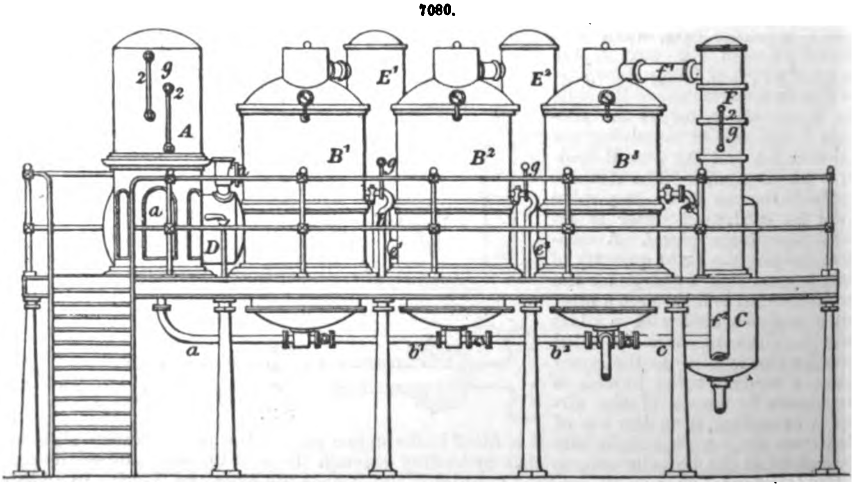
A considerable modification of the system of boiling in vacuo is that known as the triple effet, being of French origin. It consists of a set of three vacuum pans connected to one another, and is intended to evaporate the liquor from the beginning, thereby superseding the use of a naked fire altogether.

The main objects of the triple-effet pan are economy of fuel and in condensing water. In the first of the three pans there is but little vacuum, usually about 5 or 6 in. of mercury. In the second the vacuum is better, or about 12 to 14 in.; and in the third is maintained as good a vacuum as possible.

The pans are heated by steam—usually obtained from the exhaust of the mill and air-pump engines—being introduced into the first one, which, from the lowness of the vacuum, requires the most heat. The steam given off by this pan is used for heating the second, where the vacuum is better; the third pan being similarly heated from the steam of the second. The vapour of the third pan is condensed in the same manner as that of an ordinary vacuum pan.

Fig. 7080 is an arrangement by Manlove, Alliott, and Co., of this system. A is the measure

7080.



for charging the pans, connected by the pipe a to the first pan B¹, which is connected by the pipe b^1 to the pan B²; the third pan B³ being in its turn connected by the pipe b^2 to the second. This third pan is also connected to the monte-jus C by the pipe c. The first pan B¹ is heated by steam from the steam-receiver D, the vapour from this pan passing into the receiver E¹, and thence into the steam space of the second pan; a similar process being repeated with the third pan B³, to which is connected the condenser F and air-pumps. The vessels E¹, E², and F, also act as safes or tell-tales, in case the liquor primes over.

Supposing the first pan, which has a very slight vacuum, to boil at 200°, and the third, with the best vacuum, to boil at 150°, the boiling point of the second or middle pan should be 175°, or intermediate between the two. The steam from the first pan would thus be 25° hotter than the liquor in the second, and the steam in the second 25° hotter than the liquor in the third; a sufficient difference to produce a brisk boil. In this case the evaporation should theoretically proceed at

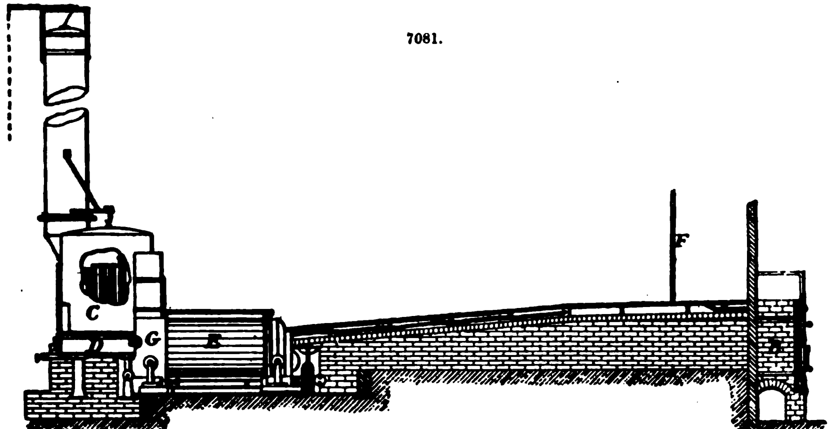
the same speed in each pan, but practically there is a slight amount of loss in the transmission of the heat.

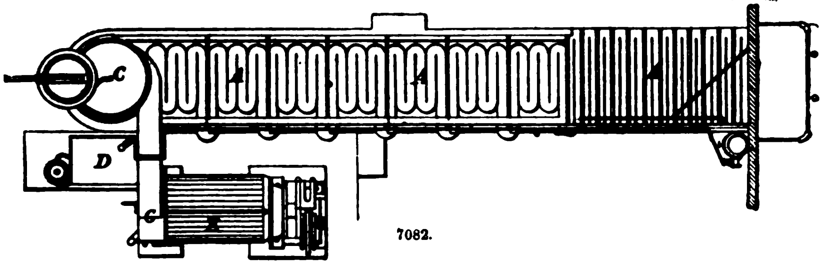
The advantages claimed for this system are economy in steam and in water for condensing the vapour of the liquor. And no doubt by utilizing the heat of the vapour twice over instead of condensing it directly, such economy is obtained, although whether it is sufficient to compensate for the increased cost of the apparatus has not been as yet determined.

Fryer's Concretor.—The only other method of evaporation which remains to be noticed was invented by Fryer, of Manchester, and is intended to evaporate the liquor to such a point that when cold it becomes a solid mass. This is only of use to the refiner, but for his purpose it appears to be well suited.

Figs. 7081, 7082, are of a Fryer's concretor by Manlove, Alliott, and Co., of Nottingham.

7081.





7082.

Fig. 7081 is a side elevation; Fig. 7082, a plan. The concretor consists of a series of shallow trays A, A, A, placed end to end, and divided transversely by ribs running almost from side to side. At one end of these trays is a furnace B, the flue of which runs beneath them, and at the other end is an air-heater C, which makes use of the waste heat from the flue, and employs it in heating air to be made use of in the revolving cylinder E. Between the trays A, A, and the revolving cylinder E, is a small tank D. The whole series of trays A, A, A, is placed on a slight incline, the upper end being next the furnace. The upper three trays are made of wrought iron, since the intense heat here would render cast iron liable to fracture. The clarified juice from the pipe F flows first on to the tray next the furnace; it cannot flow straight down the incline towards the air-heater C, because of the transverse ribs already alluded to, which oblige it to flow from side to side of the tray in a shallow stream. Thus it has to traverse a channel some 400 ft. long before it can flow away from the trays at the end next the air-heater, although the distance from the furnace to the air-heater in a direct line is not quite 50 ft. While flowing over these trays the juice is kept rapidly boiling by means of the heat from the furnace, and although it only takes some eight to ten minutes to traverse them, its density is, during this short time, raised from say 10° to about 30° Baumé.

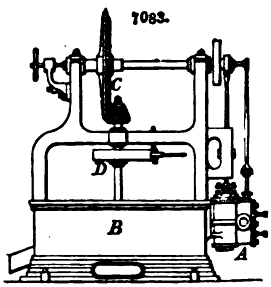
From the trays the thickened syrup flows into the tank D, and thence passes into the revolving cylinder E. This cylinder is full of scroll-shaped plates of iron, over both sides of which the thickened syrup flows as the cylinder revolves, and thus exposes a very large surface to the action of hot air, which is drawn through it by means of a fan G; motion is given to the whole apparatus by means of a small engine H. In this cylinder the syrup remains for about twenty minutes, and at the end of that time flows from it at a temperature of about 195° to 200° Fahrenheit, and of such a consistency that it sets quite hard on cooling. Thus properly-made concrete sugar forms a solid mass, not liable to drainage during transport, and ready for immediate shipment.

Curing.—This process consists in separating the uncrystallized or rock portion of the sugar, usually termed molasses, as far as practicable from the crystals of sugar, and effected by natural or artificial drainage. The old method, still in very general use, is to dig the semi-liquid mass out of the coolers as soon as it is sufficiently cold, and put it into hogsheads. These hogsheads have a series of holes bored in their bottoms, into each of which is fitted a bulrush, long enough to

extend a little above the top. After a few days these rushes are withdrawn and the molasses allowed to drain out through the holes. This process is very tedious and also very ineffectual, especially with low-quality sugar; a large proportion of molasses still remaining in the hogsheads when shipped, and constantly draining into the hold of the vessel. When the sugar has been filtered through charcoal and evaporated in the vacuum pan, as in refineries, and at some sugar estates, it is removed from the cooler, or rather the heater, into conical moulds of the shape of the loaves of sugar, and varying in weight from 10 lbs. to 56 lbs., according to the quality of the sugar. The apex of the cone, which is placed downwards, has a hole through it, which is stopped up during the process of filling and for about twelve hours afterwards. The room in which these moulds are placed is kept at a temperature of at least 100° to facilitate the drainage. When the holes at the bottom of the moulds are unstopped, the molasses—or, as it is now called, syrup—drains into a gutter placed underneath; a piercer made of steel wire being used for clearing the way at the lower end of the mould. After the syrup has drained away, clarified liquor is poured on the top, which as it filters through washes the sugar crystals without dissolving them. It is a well-known fact that sugar crystals are always colourless, and that the colour of a sample of sugar depends upon the liquor coating the crystals; if, therefore, this be washed off, the sugar assumes a perfectly white colour. In practice the lower portion of the cane is always coloured, but when the loaf is taken out of the mould, the coloured portion is knocked off, or if a handsome loaf is required, a new end, or nose, is turned on by means of revolving cutters.

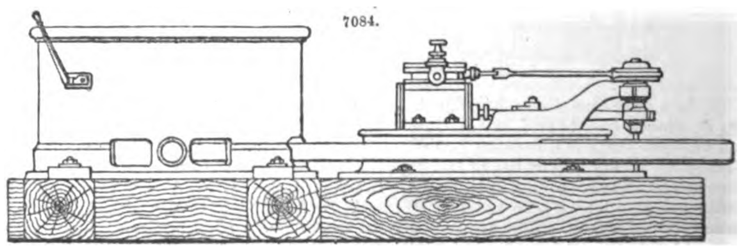
Artificial Curing.—The above process is frequently hastened by attaching the orifice of the cones to a pipe in which a vacuum is formed, and thus sucking the liquor through the loaf. This plan was invented by Hague in 1816, who first proposed the system for unrefined sugar. The uncured sugar was placed in vessels the bottoms of which were made of perforated copper and connected to a pipe communicating with an air-pump, and thus the molasses was drawn through the perforations into the exhaust-pipe. It did not, however, find favour with the planters, and it is now superseded by the centrifugal machine, excepting, as mentioned above, for loaf-sugar. Centrifugal machines were first used for drying cotton and woollen goods, and were for that reason called hydro-extractors; but about thirty years ago Lawrence and Hardman designed one for expelling molasses from sugar, since which time a great many varieties have been invented, all, however, being alike in their essential features. These consist of a cylindrical basket revolving on an upright shaft, the sides of which are made of wire gauze or perforated metal, and into which the sugar is placed. This basket is enclosed in a casing of such diameter as to leave an annular space of about 4 in. into which the molasses is expelled by centrifugal force through the wire gauze when the basket is revolving at a high speed, a spout being placed at the bottom of the casing to allow the expelled molasses to run away to a receiver.

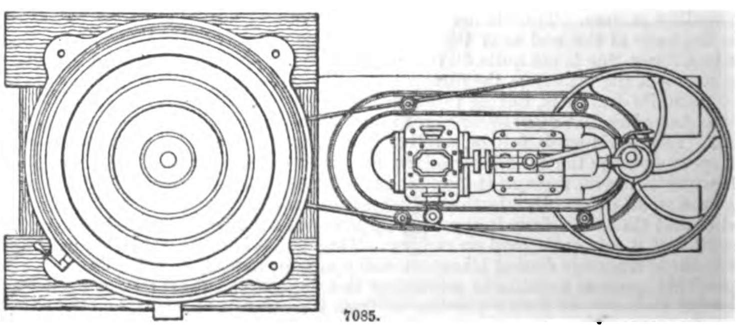
7083.



There are various arrangements of centrifugal machines, a few of the best of which are the following;—Fig. 7083 is an overhead machine, by Walker, Henderson, and Co., where the driving gear is placed above the basket. It will be seen that the basket is driven

7084.



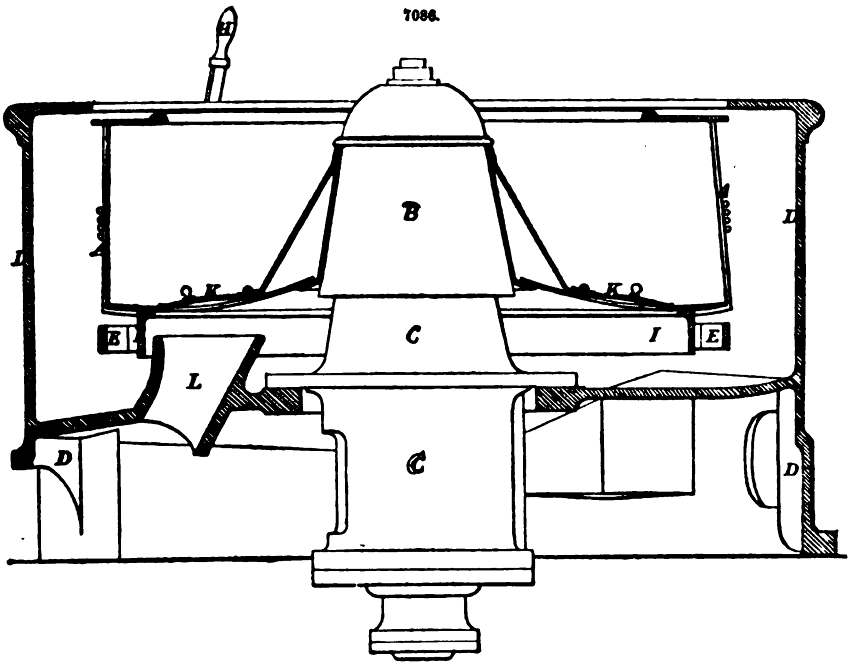


7085.

by a small upright engine A attached to the outer casing B, the speed being multiplied by frictional gearing C. A brake D is attached to the basket-spindle for convenience of stopping. Figs. 7084, 7085,

are an elevation and plan, and Fig. 7086 is an enlarged section, of a centrifugal machine, by Manlove, Alliott, and Co., Nottingham, driven by a separate engine. This method is very convenient

7086.

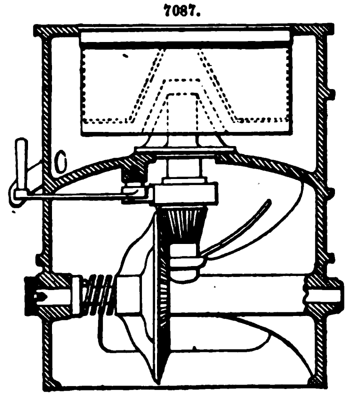


for small estates, and it also can be worked independently of all other machinery except the boiler. The machine comprises a revolving basket A, usually made of wire and carried by means of the cast-iron dome B on a central shaft arranged with driving pulley, footstep, and neck-bearing, on the central bracket C, the whole supported by the outer cast-iron casing D, which collects the water or liquor thrown off from the material in the basket, and conveys it away through a discharge-pipe. E is a brake for stopping the motion of the basket, and is applied by the lever-handle H acting upon the angle-iron ring I riveted on to the cylinder bottom. K, K, are two copper doors covering openings in the cylinder bottom, through which sugar may be discharged, passing down the shoot L cast in the outer casing into a suitable receptacle placed below to receive it.

A machine of $3\frac{1}{2}$ ft. diameter would be driven from 800 to 1200 revolutions a minute, according to the work to be done. At 1000 revolutions a minute, a machine of this size would exercise a centrifugal force of 600 times the weight of the load, and at 1200 revolutions 865 times the weight of the load; thus 1 cwt. of material in a basket going at the rate of 1000 revolutions a minute would, by the centrifugal force imparted to it, bear a weight or pressure upon the periphery of the basket of 1 cwt. $\times$ 600 = 30 tons, and at 1200 revolutions 1 cwt. $\times$ 865 = 43 tons 5 cwt.

Fig. 7087 illustrates a Lessware's machine by J. and H. Gwynne, London, the arrangement for driving being very much like that shown in Fig. 7083, only inverted. This machine is very compact, and being self-contained requires no expensive foundation. The basket, instead of being made of wire gauze stiffened by vertical ribs, consists of three casings, the inner being formed of thin copper perforated as closely as possible; round this is a casing of wire gauze, and outside these two is a sheet-copper casing, in which the holes are somewhat larger and farther apart. In the ordinary basket the sugar is liable to stick in moist lumps opposite the vertical ribs in consequence of the meshes of the gauge being closed by them; but in this case Lessware has successfully removed that objection.

7087.



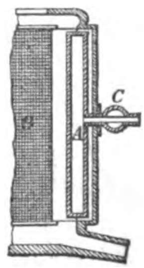
The baskets of centrifugals driven from beneath are usually hung on cones, as shown in dotted lines, Fig. 7087, and are either kept in place by a screw and nut at the top, or, in some cases, by a button, or similar catch, turned by hand; the latter arrangement is for the purpose of removing them as soon as the sugar inside is cured, and replacing them with others already charged with raw sugar; but this method has many disadvantages. As the wire gauze of the basket is liable to become clogged, especially when working with sugar of a low quality, a steam jet is fitted to the inside of the outer casing, which being turned on while the empty basket is slowly revolving, effectually cleanses the wire. In Figs. 7088, 7089 is shown an arrangement for this purpose invented in 1849 by Finzel, of Bristol, which consists

of a chamber A whose length is equal to the depth of the basket B, and which is perforated with a series of holes, so that when the steam is let on through the cock C, it impinges on the entire surface of the basket as it revolves.

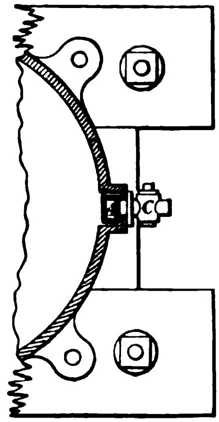
The speed at which the basket of a centrifugal should be driven is generally reckoned at 10,000 circumferential ft. a minute. Thus a 48-in. centrifugal is speeded for about 800 revolutions a minute, a 36-in. machine having to make about 1060 revolutions in the same time.

The amount of sugar that can be cured at one time by a centrifugal, say of 48 in. diameter, varies considerably with the quality. For large-grained sugar some makers put in as much as the basket can conveniently hold, or about 4½ cwt.; but most prefer from 2½ to 3 cwt. for a full charge, as it is cured more speedily and effectually. With low sugars a charge of half the above quantity is sufficient. With large-grained sugar three or four minutes, and sometimes even less, is sufficient to cure a charge; but low, sticky sugars require very much more time, or from twenty minutes to half an hour. If a very pale-coloured sugar is desired, a small quantity of hot water, or, what is better, clarified syrup, may be poured in after the molasses has been as far as possible driven out.

7088.



7089.



7090.

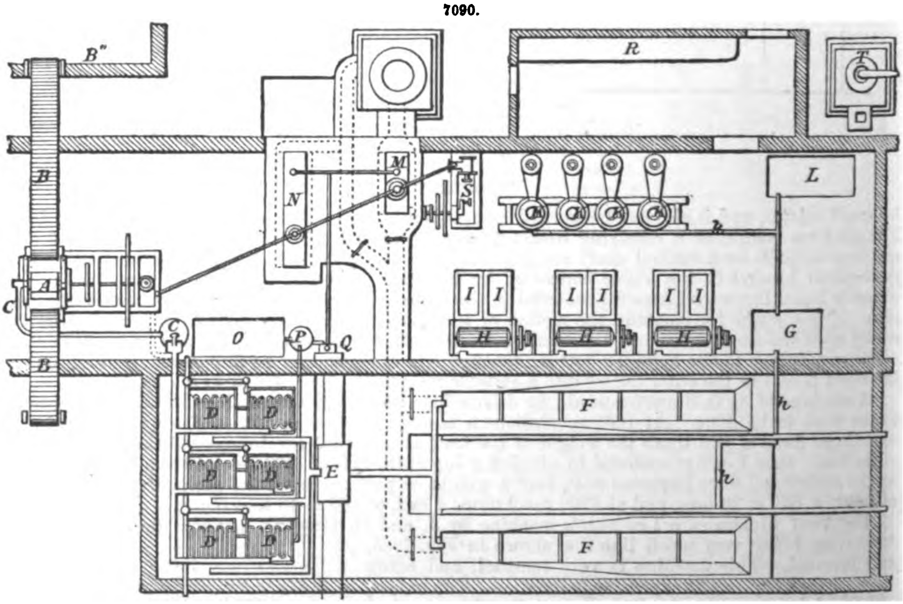


Fig. 7090 is a plan of a sugar-house, in which the apparatus already described are shown in their respective places. The cane-mill A is supplied with a cane-carrier B and trash-carrier B', which leads to the trash-house B², usually a long narrow building with a tramway running along the middle, and as high up as the roof will admit. The expressed juice runs along the gutter *c* to the monte-jus C, where it is elevated into the clarifiers D, which are placed at a sufficient elevation to allow the juice to descend through the various vessels until it arrives in the coolers by its own gravity. The clarified liquor is conveyed by the gutters *e* to the filter E. From thence it runs along the gutters *f* into the batteries F, where it is concentrated to about 27° Beaumé; when it is allowed to run along the gutters *h* into one of the Wetzel pans H, or if these are full, into the cistern G, whence it is pumped into the Wetzels as required. When fully concentrated the syrup is let down into the coolers I by movable shoots. Here it is allowed to stand until cold, when it is cured in the centrifugal machines K, from whence it is removed to be dried on the bench R. The molasses from the centrifugals is conveyed by the gutter *k* either into the cistern G or tank L; into the former for the purpose of being re-concentrated, or into the latter for supplying the still-house. In order to economize fuel a tubular boiler M is fixed in the flue of the batteries, as shown in dotted lines, the waste heat from the furnaces of which is sufficient to supply the whole of the steam required. When it is not desirable to work the boiler the heat may be conducted into the chimney by the flue *m*. The boiler N is for the purpose of supplying steam when the batteries are not being worked. The tank O is placed on columns as high as the roof will admit, and is used for washing out the clarifiers and batteries. The small cistern P to which is

attached a donkey-engine Q, is for the purpose of receiving the condense water from the clarifiers and returning it to the boilers; the tank O supplying any extra quantity of water that may be required. The engine S is for driving the centrifugals, Wetzels, and any other machinery that may be required. A still is shown at T, and the situation of still-house is by the broken walls.

SUN-WHEEL. Fr., *Mouche;* Ger., *Laüfgetriebe;* Ital., *Ruota planetaria;* Span., *Rueda para cambiar el movimiento.*

See Mechanical Movements.

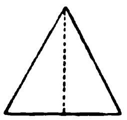
SURVEYING. Fr., *Arpentage;* Ger., *Feldmessen;* Ital., *Agrimensura;* Span., *Agrimensura.*

Surveying and Levelling.—All surveys may be classed under one of two heads, namely, those which are carried out without the aid of an angular instrument, and those in which one or more instruments are employed. The principle upon which all surveying is based, is that of dividing the area to be included in the survey into a certain number of triangles, the relative position and accuracy of which are capable of being ascertained or checked, as it is termed, by more than one independent method. Of all geometrical figures the triangle is the only one which cannot change its shape without at the same time altering the length of its sides. Provided the length of its sides be constant its form is immutable. It must not be imagined, however, that the adoption of this form ensures necessarily accurate measurement or renders errors in chaining of no consequence. Whatever geometrical form may be selected for subdividing the area of a survey, the necessity for proof or tie-lines is absolute. The time placed at the disposal of the surveyor must, to a great extent, modify the scale of precision to which he intends adhering, and the exact nature of the survey and the purposes for which it is intended will also materially influence him. When a survey is required for building purposes, where every foot of frontage is of value, extreme accuracy is not only desirable but absolutely necessary. In the simplest cases, these comprise merely the accurate measurement of a quadrangular piece of ground, which includes the frontage and rear of the proposed buildings. Upon the most extended scale they embrace the survey of large estates, the laying out of the necessary roads and routes of intercommunication, the marking out of the course of the drains, the gas and water pipes, and the taking of the levels to ascertain the contours of the ground.

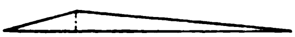
Planning a Survey.—By the phrase planning a survey is meant the acquisition of that knowledge of the ground and its principal features, which will enable the surveyor to design in his own mind the general method upon which he intends to proceed. For this purpose he must make in all cases a preliminary reconnaissance, and the principles which should guide him, are similar to those already laid down in our article Railway Engineering. Accompanied by a guide, the surveyor must walk over the ground, carefully noting all the prominent objects which may be suitable for stations, and making a rough sketch in a note-book. Whether a map of the district is procurable or not, this walking over the ground should never be omitted; but where such assistance is not obtainable it must be performed more thoroughly and extensively. A surveyor should, before commencing his field-work, have the general outline of the survey, and the general distribution of the main triangles, roughly plotted in his imagination.

Thus while a map of the county is a great convenience, and a saving of time and trouble, it is not indispensable, as a general resemblance to the actual plan of the locality is all that is really of importance. The main object sought, is the cutting up or dividing of the area to be surveyed into a number of triangles, always as far as possible consistent with the accurate determination of the various objects to be included in the survey. Upon the selection of the main or base lines depend the facility and ease with which the survey may be conducted, as well as the time which it will occupy. While the system of lines laid down must always vary with the particular shape of the parish or estate to be surveyed, yet, as a rule, the longer the lines the better, and the nearer they approach to boundaries and fences the less need will there be of offsets and subsidiary triangles. At the same time it would be a serious error to spoil a well-conditioned triangle for the sake of running one of its sides along a fence. This should be avoided, as it is not an uncommon practice, and is an example of unscientific work. A well-conditioned triangle is one in which the angles are neither very acute nor very obtuse, and in laying out triangles it should be endeavoured to make them as nearly equiangular, and consequently equilateral, as possible. This is in many cases impossible, but the principle should not be lost sight of. The advantage of keeping the triangles as nearly as possible in conformity with these rules, is that the further the figure of the triangle deviates from the equilateral, the greater will be the error incurred, if some of its dimensions be a little out. A glance at Figs. 7091, 7092, will demonstrate the difference between a well and an ill conditioned triangle. In compound or instrumental surveying, which has been treated of in Geodesy, ill-conditioned triangles are not of so much importance as in simple chain measurements, but in every case their employment is to be avoided.

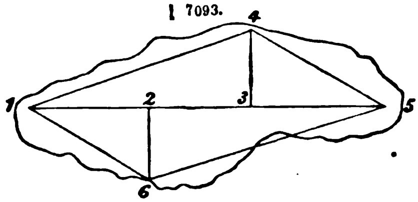
7091.



7092.



7093.

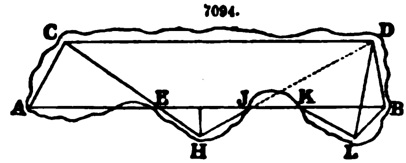


To distinguish base lines from others of a less important character, they are sometimes termed station lines. A station is the point where any main or base line commences or terminates. It may thus occur not only at these places, but anywhere along a main line wherever another line, perhaps a tie-line, may commence or end. This will be understood from Fig. 7093, which repre-

sents a piece of land to be surveyed by the chain. In the first place a base line from 1 to 5 is measured as nearly as possible through the centre of it, and the two triangles 1, 4, 5, and 1, 6, 5, constructed upon each side of it, to take in the boundaries. The two tie-lines to check the accuracy of the measurements are measured from the points 2 and 3, which are therefore stations upon the main or base line 1 and 5. There are in the figure six stations in all, and it will be shown, when we treat of the field-book, that they are distinguished by particular marks, not only for the purpose of preventing confusion, but also for the sake of guidance in plotting the work. As a general principle, liable to some exceptions, the best plan is to measure a base line the whole length of the survey, as nearly through the centre as convenient. Upon this construct as many subsidiary triangles as possible, taking care to tie them in to the main line where necessary. The diagram, Fig. 7093, is an example in point. There are, however, numerous instances where to follow this course would entail superfluous labour, and the surveyor should know how to vary his triangles to suit each particular occasion.

In Fig. 7094 is represented an estate the form of which is not adapted to the same system of lines as would answer for the example, Fig. 7093. Those shown are sufficient to determine all the points. Thus taking A B for the main line, and plotting it on paper, the point C is obtained by the intersection of the lines A C and E C, or at least supposed to be correctly obtained. It will be seen that it will be checked by another line. Having determined the point C, the point L is next obtained from K and B by the intersection of lines K L and B L. To find D we sweep a circle with the radius B D, and another with a radius equal to L D from L. If all the measurements be correct, the distance between the two points C and D will be found equal to that measured, which will close the survey. Although not absolutely necessary, it would be well worth the time to continue the line H J to D, which would, in case of error, determine at once which of the points, C or D, was wrong.

7094.

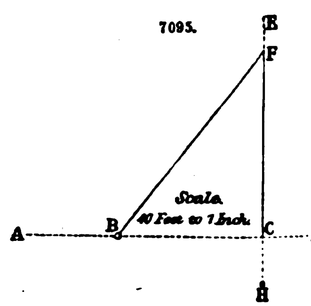


Surveying Chains.—A description of these, as well of the other instruments employed in the operations of surveying and levelling, will be found under Surveying Instruments. Our reasons for preferring the chain of 100 ft. in length to the standard chain of 66 ft. have already been given in Railway Engineering. On the continent of Europe steel tapes are preferred to chains. They have the advantage of not being so liable to stretch; but on the other hand, they are apt to become bent and even broken in bad and uneven ground, and when there is much cover in the way. As the length of a chain varies with the temperature, and also in order to provide for the readjustment of its length after it has been stretched by use, a standard length should be laid down in the immediate locality in which any survey of considerable extent is being conducted. Copings of walls, and platforms of railway stations, form convenient places upon which to mark the standard length. Should those not be available, a couple of stout stakes may be driven into the ground, and sawn off flush with it. Upon their saw-cut surfaces the standard length may be accurately marked. It is not a bad plan, as an additional precaution, to drive a third stake in the centre, and mark on it a point corresponding to the exact middle division of the chain. In testing the chain, care must be taken that the rings are quite free from dirt, and the links perfectly straight, so that the chain may play freely along its whole length.

Chaining Base Lines.—The method of doing this has already been described under Geodesy, when great care and accuracy are necessary, as in extensive trigonometrical surveys. The method is the same, whatever description of measure may be adopted. For the usual purposes of surveying, the ordinary iron or steel chain, when carefully handled, is quite sufficient.

Laying Off Perpendiculars with the Chain.—After measuring straight lines accurately with the chain, the next elementary operation is to set out a line at any angle with a given line, or to ascertain the angle between any two given lines. In small surveys, where the chain alone is employed, this is usually confined to setting out lines at right angles to a given or base line. The chain, the old cross staff, the optical square, or any angular instrument of a more complicated nature, may be used for this purpose, and the extent and importance of the line to be ranged or set out, must determine the method to be used. Where the line is short the chain may be employed for the purpose, but it is not so expeditious a mode as that by the optical square. It, moreover, involves a little manipulation, in which an error may be made, whereas the optical square performs its task with mechanical fidelity. In Fig. 7095 let A D be a base or any given line, and it is required to erect a perpendicular at C, in the direction C E. Measure off C B equal to 30 ft., fix one end of the chain at B, and let it be firmly held there. Fix the ninetieth link at C, leaving ten links loose, as shown by the dotted line C H. Take hold of the central brass, or fiftieth link of the chain, pull taut, and fix a pin at F. The line ranged through C F will be a perpendicular to A D at the point C. In books upon the subject this operation is described a little differently. For example, B C is made equal to 40 ft. instead of 30 ft. It is clear that as the line A D is fixed, and its direction certain, it is preferable to make B C equal 30 ft. and C F equal to 40 ft., thus giving a longer line to range out the perpendicular C E, which may equal 100 ft. or more. The chain must be pulled quite taut at F, as the whole accuracy of the proceeding consists in the triangle being rigidly and evenly constructed upon the ground.

7095.



In a ploughed field upon a wet day, with the links of the chain clogged with dirt, some care is required to manage the operation successfully.

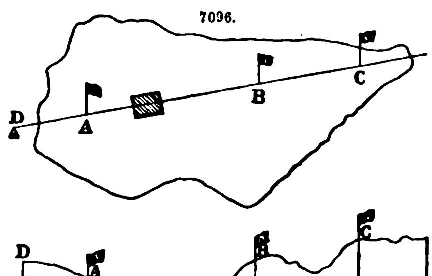
Theoretically this simple method of constructing a right-angled triangle upon the ground is founded upon the 47th proposition of Euclid. It will be perceived that $BF^2 = BC^2 + CF^2$ or $(50)^2 = (30^2 + 40^2)$. Reduced to the smallest limits the ratio is $5^2 = (3^2 + 4^2)$, and consequently any decimal multiplication of these numbers yields similarly truthful results. It is, in fact, the construction of a right-angled triangle, in which the relative equality between the hypothenuse and the remaining sides is given in integral numbers. The employment of this method is evidently limited to short perpendiculars, as it is against all principles of sound surveying to range or produce long lines from comparatively short ones. By the figure, the longest line from which to range out a perpendicular to any point C cannot exceed 40 ft., and it would not be prudent to extend this towards E beyond 100 ft., unless only approximative accuracy were demanded. This method is therefore adapted but for very insignificant distances, and, moreover, should not be used for setting out lines at right angles where they are to form subsidiary main lines of a survey. It will answer well enough for building up small triangles upon existing base or main lines, in order to get in the irregular boundaries of winding rivers or unsymmetrically-shaped woods and fences. The accuracy of the point F may be checked by an angular instrument, in order to satisfy the surveyor that the method is, first of all, a correct one, and, secondly, that he can do it correctly on the ground.

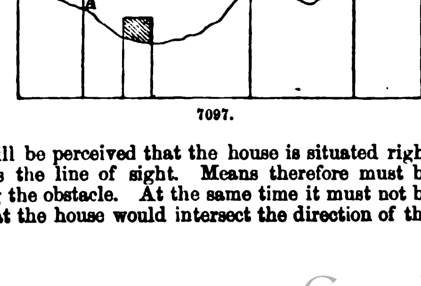
Laying Off Perpendiculars with Instruments.—A very ancient instrument for laying off perpendiculars to a given base line is the cross staff, which has been superseded by the optical square. This useful little instrument is a pocket sextant denuded of its divided arc and one mirror, and with the other fixed permanently at an angle of 45° to the line of direct vision. It is a pocket sextant capable of reading only an angle of 90°. Its essential feature is a small reflector, which is silvered on its lower half but left plain upon its upper, thus admitting of direct vision through the latter, whilst any object can only be seen by reflection upon its lower part. Suppose it be required to raise a perpendicular at any point of a given line. Select any object in the line, and, standing over the point to which the perpendicular is required, look through a hole in the instrument provided for the purpose, until that object is seen clearly through the upper or unsilvered portion of the mirror. Direct an assistant to take a ranging rod and walk in the direction of the perpendicular, until the rod seen by reflection from the silvered or lower portion of the mirror, appears to coincide with the object, or until the two objects, the one seen by direct and the other by reflected vision, overlap, as it is termed. If the object be also a ranging rod, the overlapping of the two will be very distinct, and the position of the perpendicular obtained with great precision.

Within certain limits this method of laying out perpendiculars is independent of the distance, but if the ground is very uneven it is rather tedious, and, moreover, loses some of its accuracy. When the ground is very rugged and hilly recourse must be had to the theodolite. If, instead of setting out a perpendicular from a given point on a line, it is required to find where upon that line a perpendicular from any given object situated to the right or left of it would fall, the operation is simply reversed. In that case, after having first set up a ranging rod in the line, and sighted it by direct vision, all that is necessary is to walk slowly towards it exactly along the line until the image of the object from which the perpendicular is required, is seen by reflection to overlap the ranging rod. The point where the observer then stands is the position of the perpendicular upon the given line. It is well to let the object seen by direct vision be at least a couple of hundred feet off from the point where the perpendicular is wanted, as the farther off it is situated, the better chance, comparatively speaking, of the accuracy of the result.

Obstructions in Base Lines.—However desirous it may be to run the principal lines of a survey clear of all obstacles and impediments, it is in many instances impossible to do so. In the ranging out of the line it often happens that some obstacle may intervene, which cannot be seen until the line is regularly and progressively chained out, and a near approach made to the impediment. Figs. 7096, 7097, will explain this clearly. It must be borne in mind that the chief object in laying out the main lines of the survey, is to obtain a good series of triangles, and that, provided the line selected is well adapted for this purpose, it would be extremely injudicious to divert it, or break it up, in consequence of a trifling impediment lying in its path. The best line should be selected and adhered to, in spite of all obstacles and impediments, which merely require care and trouble to be successfully overcome. In Fig. 7096 suppose the base line to have been ranged from D to C. From the point D the other end of the base line can be seen at C, and intervening rods can be put up in the line of sight at A and B. There is, however, an impediment in the shape of a house situated right in the line D C, which cannot be seen from either D or C. A reference to Fig. 7097, which shows a section of the ground along the base line D C, will demonstrate the reason of this. The house lies in a hollow, and is evidently invisible from either end of the line. After having ranged out the line, and proceeded with the chaining as far as the first point A, it will be perceived that the house is situated right between A and the next point B, and interrupts the line of sight. Means therefore must be taken for overcoming the difficulty, and for passing the obstacle. At the same time it must not be assumed, that even had it been distinctly seen that the house would intersect the direction of the

7096.



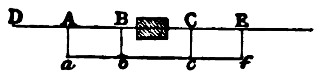


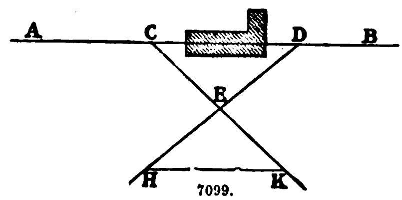
7097.

base line, it should therefore have been abandoned, and another run so as to clear the house. It is true that the actual shifting of the line at the point where the obstacle occurred, might not exceed a dozen feet to one side or the other, but this dozen feet in a base line a mile long would throw the end out to a very great extent, and in all probability render it useless as a main line of the system of triangulation proper to be adopted under the circumstances.

The majority of the methods employed for passing objects which interfere with the direction of base lines, depend upon one or other of the problems of Euclid, including those relating to the properties of similar triangles. The direct measurement should always be obtained where possible, and will in all cases be found more satisfactory. The methods which we are about to illustrate, only apply to examples where the interruption is of a very limited nature. Where long distances have to be determined with accuracy, there is no other plan of ascertaining them than by the use of the theodolite and trigonometrical calculation. One of the simplest instances of an obstruction is represented in Fig. 7098, where it is required to pass a house which is intersected by one of the main lines. The plan to be pursued consists in setting out a line parallel to the main line for a distance sufficient to clear the obstacle, and then resuming the former direction. At some reasonable distance from the obstacle let a perpendicular be laid off with the chain from the point A, and the distance A *a* very carefully measured. At the point B set off another perpendicular B *b*, of the same length as A *a*. The distance *a b* should be of a length proportional to the length of the obstacle to be passed, as it will determine the direction of the parallel line. This is obtained by ranging a line through the points *a* and *b*. After passing the obstacle at the point *c*, set off the perpendicular *c* C of the same length as those already laid off at A and B. The point C will be in the direction of the original base line, and by sighting from C to the next point visible on the main line, the correct direction can be continued. Should it, however, be impossible to see any of the points on the main line previously determined, the direction may be obtained by laying off from *f*, on the parallel line the perpendicular *f* E equal to *c* C. By ranging through C E the base line may be continued until one of the more distant points can be seen. If this operation is carefully performed, it will be found on checking the direction of the next point arrived at, that the deviation will not exceed two or three inches, which may be regarded as practically of no consequence. The essential points to be attended to, are the accurate measurement of the perpendiculars, and the ranging of the parallel line. It would be very imprudent to range a line on, from the other side of the obstacle, by this method, without determining some distant point beyond it, to act as a check upon the direction, for a slip of an inch or two at the obstacle might become a serious error at the end of the line. So long as the two extremities of a line are fixed, it is comparatively easy to maintain the intermediate points in the proper direction.

7098.





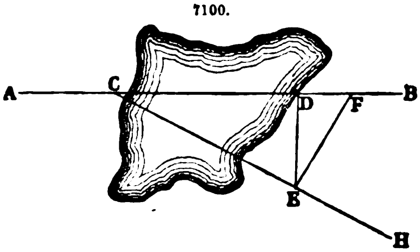
7099.

Whenever the line has been ranged, and its direction fixed by points at each extremity, one of which is visible from any given obstruction, the obstacle may be passed in a simpler manner than that already described, and one which avoids the laying off of the perpendiculars, and the consequent possibility of errors taking place. Let it be required to pass the house in Fig. 7099, situated in the line A B, the points A and B being already determined, and the latter visible from the place where the house stands. At the point C range a line C K, making C E = E K. Then, from any point D in the direction of the base line, range D H through the point E, making D E = E H. The line H K will be equal to the line C D, and the chaining may be proceeded with from the point D, after adding the distance H K = C D to the distance already chained. In performing this operation on the ground, care should be taken to make the triangles as well-conditioned as possible, avoiding all very obtuse and very acute angles. As, within certain limits, the selection of the points C and D is optional, there will be no difficulty in arranging them, so that the triangles C E D and E H K should be of the form required. When these departures from the regular chaining of the main lines take place, it is advisable to make a small sketch in the field-book, showing the obstacle, the distance at which it occurs, and the manner in which it is passed. We have hitherto regarded the obstacles lying in the line of sight of the base line to be of a solid nature. Frequently, however, they are merely superficial, at least so far as the surveyor is concerned, and similar examples are to be found in rivers, lakes, and ponds. In fact, it is impossible to carry out a survey, having any pretensions to size, without encountering some of these impediments. An error fallen into in most of the text-book on surveying, is that of supposing and taking as the basis for illustration, that the line crosses the river or other impediment exactly at right angles with the banks. This is a great mistake, as in nearly every instance it will happen that the line crosses on the skew, and sometimes very obliquely. It is a bad plan to attempt to work out a problem in surveying on the ground, without having previously solved it on paper or in the head. It should first be studied theoretically, and the theory of it satisfactorily demonstrated to be sound, and then it may be safely carried out in the field.

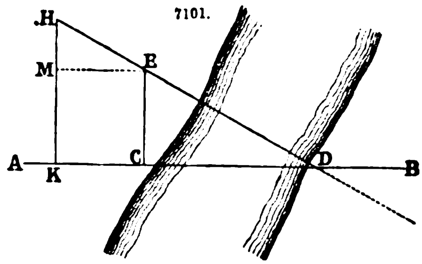
As an example of distance inaccessible to chaining, suppose a large piece of water to be crossed by the base line of a survey, as represented in Fig. 7100. Let A B be the base line, C D the distance required. Standing at C, range any line C E. From D, set off D E perpendicular to the base line, intersecting C E in any point E, and from E set off E F perpendicular to C E, and meeting the base line in F. Should there be any difficulty in getting a sufficient length of line between E and the water to lay off the perpendicular E F from, the object may be accomplished by producing C E to H, and setting off the perpendicular from the prolonged part E H. Having correctly constructed the triangles on the ground, it now remains to calculate the distance required. In the first place,

the triangles D E F and D E C are equiangular, as may be easily demonstrated thus;—Angle C D E = F D E = 90°. Angle C E F = 90° = D E F + D F E. But angle C E F = C E D + D E F, and consequently D E F + D F E = C E D + D E F. Subtracting the common angle D E F from both sides of the equation, we have angle D F E = angle C E D. Consequently the

7100.



7101.

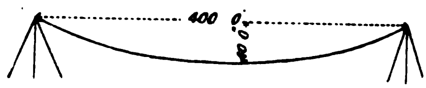


remaining angle D C E in the one triangle equals the remaining angle D E F in the other, and the two triangles are equiangular. By the sixth book of Euclid, we have the following proportion between the sides. D F : D E :: D E : D C. Multiplying extremes and means, we obtain D F × D C = D E² and $DC = \frac{DE^2}{DF}$ the distance required. To take another case, let us suppose a river has to be crossed by the base line A B in Fig. 7101, and the length C D is the measurement wanted. We will first describe the practical part of the operation, that is, the construction of the diagram on the ground, and then demonstrate the truth of it theoretically. Measure the distance K C, range any line D E H, and from the points K and C raise perpendiculars C E, K H to the base line A B, meeting the line D H in E and H, taking care to measure very carefully the length of the perpendiculars C E and K H. The required distance C D will be given by the formula $CD = \frac{CE \times CK}{KH - CE}$. Now for the proof. Draw in the figure the dotted line E M perpendicular to H K. Then the triangles H M E and E C D are similar and equiangular, because since the line H D cuts the two parallel lines H K, E C, by the first book of Euclid, angle D E C = angle E H M. For the same reason, since M E and K D are parallel, the angle H E M = angle E D C, and as the remaining angle in each triangle is each equal to 90°, the two triangles are equiangular. It follows from this that we have the following proportions;—H M : M E :: C E : C D. But H M = K H − C E, and M E = C K. Substituting these values in the above ratio, we have K H − C E : C K :: C E : C D. Multiplying the extremes and the means, we obtain (K H − C E) × C D = C E × C K, and, finally, $CD = \frac{CE \times CK}{KH - CE}$, which is the same as the formula given above. If the distance C D be considerable, and it is desirable to check the accuracy of the operation, the line H E D may be ranged on further upon the opposite side of the river in the direction of the dotted line, and the distances D E, E H having been measured along it, perpendiculars may be dropped from them upon the base line, which should be equal to K H and C E respectively. If this is carefully and correctly performed, the error will be very trifling either in direction or amount. Occasionally, instances will occur where the surveyor must, so to speak, invent a method of his own, but if he thoroughly understand the principle upon which all such problems are founded, he will have no difficulty in applying them to particular examples for which no general rule can be laid down.

Before leaving the subject of horizontal inaccessible distances, a few words may be said respecting one that was of a most important nature and somewhat difficult to obtain, the more especially as minute accuracy was indispensable. The instance in question was the determination of the centre spans of the Menai Tubular Bridge. They are 460 ft. wide in the clear, and as no temporary platform of any description could be erected, it was exceedingly difficult to ascertain the distance by direct measurement. It was, of course, effected trigonometrically, but a plan was formed to obtain it by what might be termed indirect measurement, inasmuch as it did not involve the use of any angular instrument, but depended upon the properties of the catenary. Two plans were put into execution. The first consisted in hanging a strong copper wire from a given height upon each shore, in such a manner that it assumed the catenary curve, and its lowest point just touched the surface of the water when it was quite calm. The level of the water having been accurately determined, the wire was then suspended under precisely identical conditions upon the shore, and the horizontal distance or chord of the arc accurately measured. By the second plan, the span itself was actually measured in a direct manner. For this purpose a number of deal rods were threaded on a rope, and on a calm day gently floated on the water, until they came pretty nearly into the position required. They were then drawn, by means of the rope, into a straight line, and as proper care was taken that their ends were in close contact, the span between the piers was accurately determined. All these three methods, namely, the trigonometrical one and the two just described, tallied perfectly in their respective results. It is evident that there was no absolute necessity for erecting the wire upon shore in order to obtain the length of the span or chord, for as the length of the chain, that is, of the arc, was known, and also the abscissa or versed sine, the chord or span could be obtained by calculation. Tables have been compiled giving their relative dimensions, and it is clear that if the proportions be once known for any three dimensions, they can be ascertained for any multiples or submultiples of them. Thus, if S be the half span of the chain, V the versed sine or distance of the lowest point of the curve below the horizontal line, and L the length of the arc,

then whatever particular case may be selected as a datum, it will furnish a basis for the calculation of others in which the above conditions prevail. If for certain values of S and V, L be found to have a value of x, then if the S and V become equal to $y \times$ S and $y \times$ V, the value of L will be equal to $y \times x$. For instance, in the tables of Davies Gilbert, when S = 100, and V = 20, L = 102·6. Consequently when S = 200 and V = 40, then L = 205·2 = length of half chain. The accuracy of this may be checked by the well-known formula, applicable to the determination of the length of a suspension of chain when the chord and versed sine are known. Using the same notation, but bearing in mind that L, in this instance, represents the length of the whole chain, we have $L = 2\sqrt{\left(\frac{S}{2}\right)^2 + \frac{4\,V^2}{3}}$. Substituting in this formula our values, S = 400 V = 40, the equation becomes $L = 2\sqrt{40000 + 2133 \cdot 33}$. From this, L = 2 × 205·2 = 410·4 which is exactly double the half chain found from the tables. A diagram of this is shown in Fig. 7102, which exhibits the deflection of a catenary of the above dimensions.

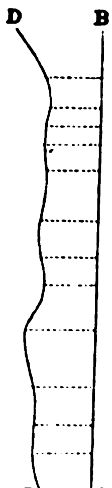
7102.



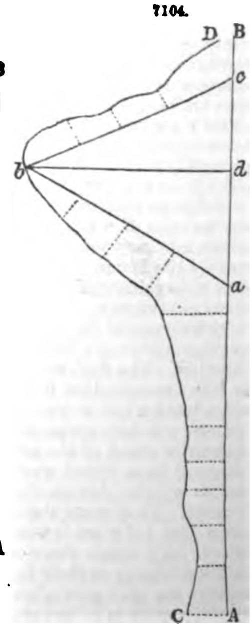
It is evident that in those instances in which the intervening space, which cannot be directly measured, has to be spanned by a structure of iron, great accuracy is indispensable. The ironwork is constructed, and often partially put together, before it is brought to its permanent site. Any discrepancy in the measurements would then be very serious and only remedied at a great expense. In erecting suspension bridges of large span, in which the distance between abutments has to be ascertained by triangulation, or what may be termed indirect measurements, the centre link of the chain is generally the last manufactured, so as to leave room for any slight adjustment in the total length which the direct measurement of the span might render necessary.

Offsets should not exceed 50 ft. or 60 ft. in length, and should invariably be taken at right angles to the main or principal line. Where great accuracy is desirable, or where a long offset is taken to a somewhat important object in the survey, the right angle may be laid off by either the optical square or by the aid of the chain only. Under ordinary circumstances offsets are most rapidly and conveniently measured with a tape, and the eye may be relied upon to give the right angle with sufficient precision for all practical purposes. It may be mentioned that there are two descriptions of tapes; one is usually known as the metallic tape, and has delicate copper wires or threads interwoven with the substance of which it is composed. The other kind is a plain linen tape without any such additional combination. When really good, either of them may be trusted at any time to half an inch. In using a tape in wet weather, or upon any occasion when it gets wet, it should never be rolled up until it is quite dry. Winding up a wet tape and laying it by in its box until it is next wanted, is a certain means of spoiling it. The tape, after being washed, should be coiled loosely up, and after carrying it for a short time in the open air it will be dry enough to wind up. The same remark applies to rolling up a dirty tape.

7103.



7104.



The same care should be bestowed upon the chain. Unless a chain is properly put up, the links are liable to get strained and bent, to say nothing of the smaller space it occupies and the handy manner in which it can be carried when nicely packed.

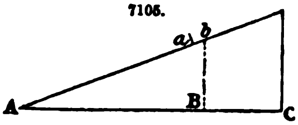
To illustrate the use of offsets in ascertaining the actual boundary of any piece of ground, or any fence that may serve as a division between different plots of land, we select the example, Fig. 7103. Let A B represent a portion of any main line forming one of the sides of any of the principal triangles laid down in a survey, and suppose it be required to determine the figure of the fence C D, the line A B having been plotted upon paper, and the respective distances along it where the offsets are set off having been marked either with the fine point of a pencil or with a pricker, let perpendicular lines be erected at these parts, and upon them the lengths of the offsets laid off. The length of each offset will be the distance from the main line to the fence C D; and consequently these distances having been laid off, the end of each offset gives a point in the fence. If all these points or ends of the offsets be joined by lines, the shape of the fence or boundary will be determined. The dotted lines represent the offsets. The example selected in Fig. 7103 assumes that the main line runs along or skirts the boundary within the prescribed length for offsets. This should always be arranged if possible, but it frequently happens that fences are so irregular as to preclude this ready manner of determining the position of their different points. Sometimes a fence will break away suddenly so as to be beyond the reach of offsets taken from the main line. This case is represented in Fig. 7104; the course to be pursued under the circumstances is shown in the diagram. When the distance from the main line A B is too great to reach the fence by the ordinary offsets, a small triangle must be constructed on the main line, and offsets taken from its sides to the fence. In the figure the triangle $a\,b\,c$ enables the fence

to be got in on the survey. The tie-line $b\,d$ must not be forgotten, as it serves as a check upon the accuracy of the work, as already explained. Although extreme accuracy is not generally needed in taking offsets in the open country, yet in the survey of cities and towns they must be determined very carefully, as the frontages of houses, the areas of gardens, out-premises, and other buildings, depend upon the care with which the measurements are made. Referring to Fig. 7103 it will be seen that there is no necessity for taking more offsets than what are sufficient to obtain every change of direction in the fence, as it is always supposed to lie in a straight line between any two successive offsets.

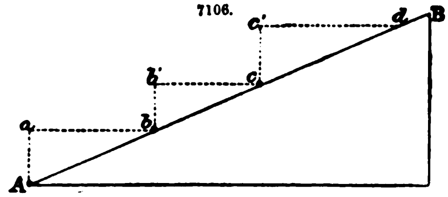
The offset staff is also used by surveyors, but is only suitable for offsets of very limited dimensions. It is usually about 6 or 7 ft. in length when the standard chain is employed, but 10 ft. is a convenient length when surveying with the chain of 100 ft. At one end of it there should be an obtuse pointed iron ferule with a steel point for sticking in the ground. At the other end there should also be an iron ferule, but without any point on it. Instead, it should have a strong hook attached to the side, and of a size large enough to hold in it the handle of the chain, which renders it useful for dragging it through hedges. Having lined out the length of the offset, the staff is turned over end for end as many times consecutively as may be required to bring it to the point to which the offset is to be taken. For this reason the offsets should be limited in length, as errors accumulate rapidly even with the most dexterous manipulation of the staff. When the offset is about 50 or 60 ft., the measurement with a tape is far preferable, and in every instance its use will be more advantageous than that of the staff.

Measurement of Hills.—In chaining and the measurement of base lines, it has been assumed that the ground has been level, or sufficiently so to cause no appreciable difference between a truly horizontal measurement and that taken along the surface. It is seldom, however, that a base line of any considerable length can be measured, without it being necessary to make some allowance for the sloping and irregular contours of the ground. The necessity for this becomes more apparent as the surface of the ground departs from the plane of the horizon, as the greater the angle of inclination the greater will be the difference between the false and the true, or the inclined and horizontal measurement. There are various methods of arriving at the true horizontal measurement of sloping surfaces, and the degree of accuracy to which the survey is to be carried, must in all cases determine which is to be adopted. It is scarcely necessary to mention that the true distance will always be less than the apparent one, and therefore, when calculation is used, there will always be a reduction to be made. An experienced surveyor is able to tell pretty well by the eye, the allowance to be made in the majority of instances when only approximate accuracy is demanded, and the question becomes reduced to taking the next measurement or chain's length, not from the end of the former, but from a point obtained by making the proper allowance. The diagram in Fig. 7105 will render this operation perfectly clear, but it is one that an inexperienced person will do better not to attempt to carry into practice. In Fig. 7105 suppose the chain to be stretched upon the inclined surface of a hill and extend from A to a, but the real horizontal measurement to extend from A to B. The point B where the chain A a will intersect the horizontal is found by taking A a in the compasses and sweeping a circle until it touches the horizontal line A C in B. If the line B b be projected at right angles to A C it will intersect the surface of the ground at b, so that the true distance to be measured along the slope by one chain's length is not A a, but A b. From the appearance of the slope an approximate estimate can be made of the distance $a\,b$, and the next chain's length is measured consequently not from a, but from the point b, and so on, as often as may be required. The same process applies to the case of a descent as well as that of an ascent, but it is invariably more difficult to arrive at a correct approximation of the rate of inclination when descending than ascending a slope.

7105.



7106.



The explanation of the method by which the distance $a\,b$ is estimated will serve to indicate a mechanical mode of arriving at the same result. This latter is preferable when carefully performed to that given in Fig. 7105. It should not, at the same time, be repeated too often consecutively, as small errors creep in at every step. Let A B in Fig. 7106 be the sloping ground to be measured horizontally. The principle consists in taking up the chain in short lengths and holding one end vertically over the starting points, while the other is fixed or held firmly down. In the figure let the surveyor be supposed to stand at A, with the end of the chain held vertically over the point A by means of a plumb-line and bob. In the meantime the leader has hold of the twenty-fifth link, which he fastens down in the proper direction at b; the surveyor then slacks the end of the chain, advances to the point b, takes up the chain carefully at the twenty-fifth link, leaving the pin in to mark the spot, and holds it over the point b, or, in technical phraseology, plumbs it over the point b. The leader has advanced to the fiftieth link, which he has fixed at c, and the operation proceeds in a similar manner to d, and until the summit of the incline is surmounted. The chain must be well stretched between the points at $b'\,c$, $c'\,d$, in order to render the deflection inappreciable, so that it is preferable to take short lengths at a time, instead of long ones, although the former may demand more trouble. The steepness of the slope will also regulate the distance between the successive points of measurement, as the chain can only be raised a certain

height by hand, and it is absolutely necessary that it be maintained as nearly horizontal as the circumstances of the case will allow. If this mechanical reduction of the inclined to the horizontal measurement be carefully performed, the result will be a very close approximation to the true distance. Should the hill be very short, the incline may be measured very expeditiously in the manner described by means of a good tape, provided there is very little wind blowing.

Having described the two approximate methods of reducing the sloping to the horizontal measurement, it now remains to indicate the more exact means of obtaining the same result. It is hardly necessary to observe that in large and important national and trigonometrical surveys, approximate methods cannot be employed, but all the operations must be performed with the most minute accuracy. A glance at Fig. 7105 will point out that there are three sides in the triangle A b B, one only of which is known. By the rules of proportion, as well as of equations, when one of these indeterminate quantities is to be determined, two must be given in order to solve the question. In the triangle A b B, the distance A b is given; and if B b were known, the horizontal distance could be ascertained, since $(A\,b)^2 = (A\,B)^2 + (B\,b)^2$, or making A $b = x$, A B $= y$, and B $= z$, we have for the value of A B, $y = \sqrt{(x^2 - z^2)}$. But B b is the difference of level between the points A and b, which can be readily obtained by levelling, as will be shown when treating of that branch of the subject. If, instead of the distance B b being known, the angle of inclination or the angle B A b were ascertained, the problem could be solved equally readily. Suppose, for instance, a certain number of feet were measured along the slope in Fig. 7106, from A to B, the correct horizontal measurement of which was A B, but which has to be determined; let A B = N′, A b = N, and θ equal the angle of elevation B A b. By the rules of trigonometry for solving right-angled triangles, we have N′ = N × cosine θ, consequently the difference between the horizontal and the sloping measurement varies as the cosine of the angle of elevation, or, in plain terms, with the slope of the ground. The difference between these two measurements, or what is called the reduction, is evidently equal to (N − N′). As an example, suppose N or the distance A b in Fig. 7106 to measure 100 ft., and the angle B A b 15°, what is the value of the correct horizontal measurement A B, and of the reduction (N − N′)? By the rule we have

$$A\,B = A\,b \times \text{cosine } 15^\circ = 100 \times 0\cdot96592 = 96\cdot592 \text{ ft.}$$

The reduction, therefore, is equal to 100 − 96·592 = 3·408 ft. The correct distance to be entered in the field-book from A to b is 96·592 ft., but if there is no necessity for noting the point b' on the plan, the simplest method will be to add 3·408 ft. to the 100 ft. already measured, and commence the next chain's length from that point. In other words, 100 ft. on the horizontal measurement equals 103·408 ft. on the sloping surface. From the formula and example we have given, it is readily perceived that tables can be constructed giving the reduction to be made, or the difference between the horizontal and sloping measurement for different angles of inclination. In Table I. is shown the number of feet on a sloping surface inclined at various angles that corresponds horizontally to 100 ft. measured along the given slope, and also the reduction to be made for every chain's length or 100 ft. measured along the slope;—

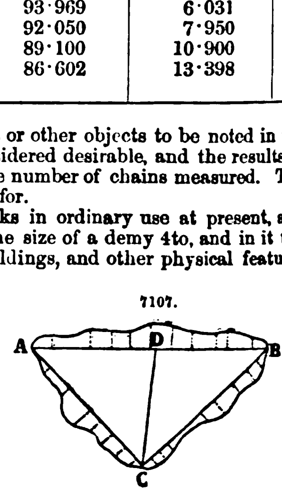
TABLE I.

Angle of Slope in degrees.	Value of 100 feet measured horizontally.	Difference or Reduction.	Angle of Slope in degrees.	Value of 100 feet measured horizontally.	Difference or Reduction.
3	99·862	0·138	16	96·126	3·874
6	99·452	0·548	18	95·105	4·895
7	99·254	0·746	20	93·969	6·031
10	98·480	1·520	23	92·050	7·950
12	97·814	2·186	27	89·100	10·900
14	97·029	2·971	30	86·602	13·398

If the slope continue uniform, and there are not any fences or other objects to be noted in the field-book, the chaining can be continued as far as may be considered desirable, and the results in the third or sixth columns given in the Table multiplied by the number of chains measured. The product will give the total reduction or difference to be allowed for.

The Field-book.—There are but two descriptions of field-books in ordinary use at present, and one of these is fast becoming obsolete. This latter is about the size of a demy 4to, and in it the triangles, lines, and offsets, together with the fences, rivers, buildings, and other physical features of the ground surveyed, are actually sketched. The dimensions are written alongside the various lines and offsets, and the whole is in fact a mere sketch-plan. The other field-book and the one to be preferred, consists of an ordinary pocket-book opening lengthways, with a couple of red lines about ⅜ in. apart, ruled in a longitudinal direction down the centre of every page.

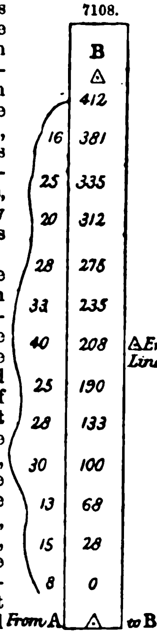
7107.



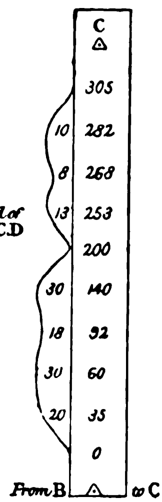
If Fig. 7107 represent a field to be surveyed according to the lines and offsets there laid down, it represents also the manner in which the measurements and lines would be sketched out in the first of the two field-books under mention. There would be in addition, of course, the dimensions of the different lines, which would be entered alongside of them, or sufficiently close to them to indicate to which they belong. Judging solely from the small example given in Fig. 7107, this description of field-

book would appear to leave nothing to be desired; but it is one matter to have to survey a single field, and another to undertake a duty involving many hundred fields, together with a large number of buildings. The great difficulty in using a sketch note-book, where the survey is on a large scale, is to avoid confusion. Omitting all further consideration of the sketch field-book, let us now pass on to investigate the other description. Referring to Fig. 7107, we are required to survey the field shown thereon, and record the measurements in the field-book so that they may be accurately plotted therefrom, and the true figure of the field drawn upon paper. In the first place it must be borne in mind that the field-book is commenced at what would, strictly speaking, be considered the last page. The object of this is that the surveyor is always looking in the direction of the line he is going, both in the field and in the field-book. The meaning of stations has already been explained as those points wherever any of the lines constituting parts of the triangles begin or end. There are various ways of distinguishing them. We prefer a small triangle with a dot in the centre, more especially as it is the same mark used by the English Ordnance engineers for distinguishing their trigonometrical stations. Commencing at A, the surveyor puts up a rod or pole at B, or any object already existing there will answer the purpose, provided it is straight and can be seen from A. After stretching out the chain in the direction of the line A B, he takes his offsets at the points shown. Returning to the field-book, Figs. 7108 to 7110, he enters in the space between the ruled lines the distance along the line where the offset occurs, and to the right or left of the space the distance in feet or links, according to what measure he is using, from the line A B to the fence or other object. This distance constitutes the offset. As the surveyor is advancing from A to B, all the offsets will be on the left-hand side of the line, and consequently plotted to the left of the space in the field-book. On arriving at 208 on the line A B, the end of the tie-line C D comes in upon the right-hand side of A B. According to what has been already stated, this constitutes the point 208 a station, and it is therefore entered as such in the field-book. The remaining lines and offsets are obtained and entered in the same manner, and the converse of the problem is to transform the contents of the field-book into the diagram represented in Fig. 7107. This is the simplest case that could possibly occur in surveying, but although the field-book becomes rather more complicated where the survey embraces large estates and towns, yet if the principle be once thoroughly understood, the more difficult examples will give no trouble afterwards.

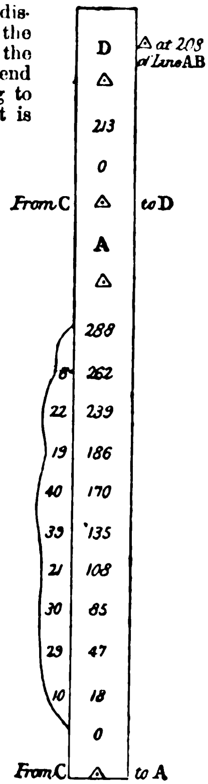
7108.



7109.

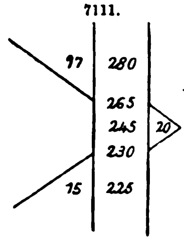


7110.

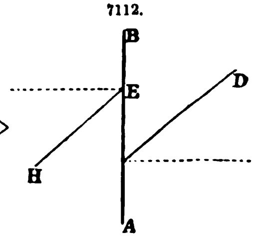


In the simple case to which reference has been made, the offsets were all taken on the same side of the main lines composing the triangle, but there might be objects situated on both sides of those lines. If the line, for instance, crossed a road or fence, there would be part of it upon the right-hand side and part of it on the left, and at the point where the crossing took place the offsets would, so to speak, change from the one side to the other. There is just one little detail that has to be attended to here, which will render the plotting of fences, roads, and other objects crossed by the main line of a survey sufficiently intelligible. It must be borne in mind that the space in the field-book enclosed between the two longitudinal lines in reality is supposed to represent the main line itself, and consequently it is advisable not to have a thickness greater than an ordinary ruled line upon paper. At whatever angle therefore the line may cross the fence, it will always appear as if it crossed it at right angles. This is shown in Fig. 7111, where a fence is represented as crossing the main line twice; once at 230 and again at 265. The direction of the fence, or the angle at which it crosses, is obtained by the offsets taken on each side as near the crossing of the fence as may be convenient. In the figure the offsets at 225, 245, and 280 determine the direction of the fence with sufficient accuracy for all practical purposes.

7111.



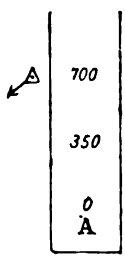
7112.



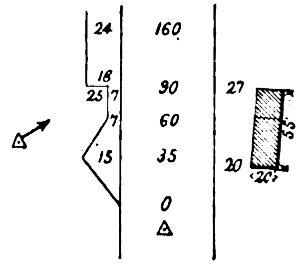
In addition to marking, by means of the station point we have chosen, the positions of the junctions of lines with others, it is advantageous to know in what direction they proceed, without having the trouble of laying down a number of tie and other lines to determine it. Suppose in changing

the line A B we run a line from C in the direction C D, and another in the direction E H, it is well to know when marking off the points C and E upon paper, on what side of the perpendicular line those lines respectively lie. Let Fig. 7112 represent the portion of the field-book belonging to Fig. 7113 in which the distances C and E correspond to 350 and 700 ft. respectively upon the main line A B. The direction of the lines C D and E H is indicated by affixing a little arrow to the station point, pointing to that side of the right angle upon which the end of the lines is situated.

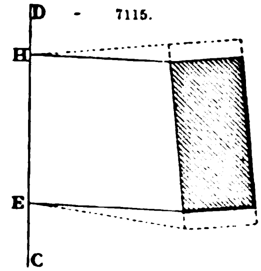
7113.



7114.



7115.

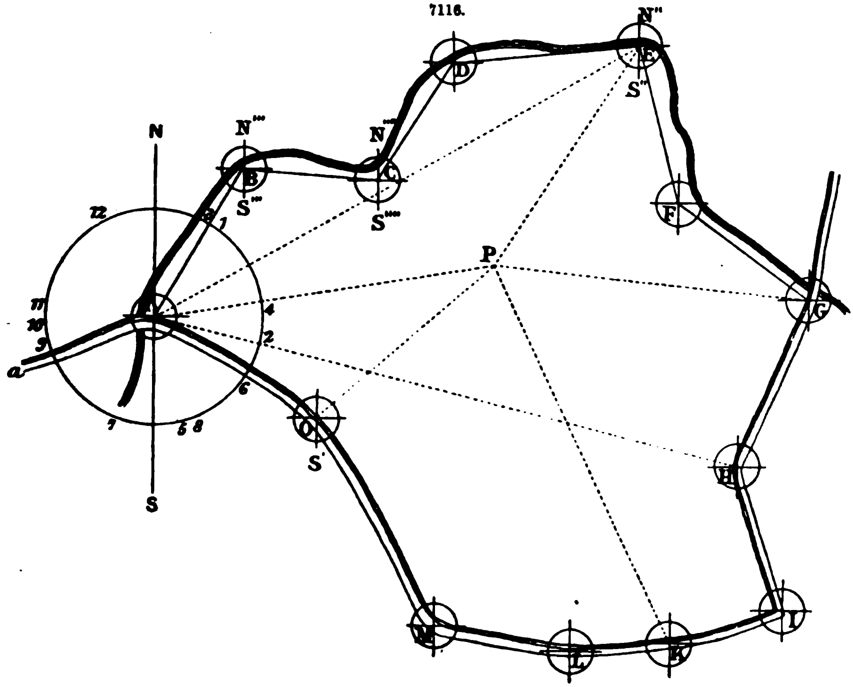


Whenever a fence makes a bend at right angles to the main line there are evidently two offsets to be entered in the same line. In Fig. 7114 let the fence bend as shown. Then it is optional whether the first offset be written by itself and the second along the bend, and the total distance to the outer line of the fence be regarded as the sum of the respective distances, or whether the offsets be written instead of 7 and 8, 7 and 25. In the latter case the outside offset, 25, is the total distance to the extreme point of the fence. There is a convenience in making the outside offset represent the total distance, arising from the fact that as the tape is already pulled out for the first measurement, it is only necessary to pull it out a little further to obtain the second, and the two are thus really got at one operation. In the other case, where they are entered separately as distinct offsets in the field-book, the tape must either be rolled up, after taking the first offset, and pulled out again to measure the second, or a mental subtraction of the one offset from the other made to obtain and enter them independently. Mental calculations should where possible be avoided in the field, as there is no check upon them, and it is sometimes very difficult to remember afterwards how they were arrived at. To ascertain the position and dimensions of a house or building as in Fig. 7115, it is only necessary to take offsets at each end, the length of the house being given by the distance along the main line they are situated apart. Although this is sufficient if correctly done, yet a very little error incurred by not measuring the offsets, especially if they be long ones at right angles to the main lines, might make a serious difference in the actual length of the building. Let us suppose that the position of a house is accurately represented in Fig. 7115, with respect to the main line C D, by the offsets from E and H being correctly taken at right angles to C D. But if the offsets were, as they might easily be through carelessness, taken in the directions of the dotted line, then the house would occupy the position shown by the dotted lines, and its length would be increased about a third more than the actual dimension. The proper way is to first take the offsets in the ordinary manner, and then measure the building all round. This is the more necessary, as in country districts buildings are not always constructed square, and frequently there is a very appreciable difference in the length of the back and front. Should a building, with a number of outhouses, such as barns, sheds, cow-houses, and other descriptions of rear premises, be enclosed by a fence or wall, it will be found a simpler and preferable plan to take the offsets only up to the enclosing wall or fence, and make a separate survey of the area and buildings within. In an extensive survey, also, it is the usual practice to first measure the main lines without taking any offset whatever. They are then laid down upon paper, and if the survey close, that is, if they agree both in length and direction, and the triangles also, they are then chained over again, and the offsets taken in the ordinary manner. The reason of this manner of proceeding is obvious. As it is always possible errors may occur, let us suppose a base line a couple of miles in length measured, and the position of objects in its vicinity determined in the ordinary manner by offsets. Now upon plotting the triangles, it is found they will not close, and consequently some errors have been made. Upon examination, it is discovered that the position of the above line is wrong, that it has, in fact, been incorrectly ranged. The result is, that the whole of the time and labour expended in taking the offsets is lost, and the only thing to be done is to draw the pen across the pages of the field-book and start afresh.

Traverse Surveying.—A traverse is the survey of a polygonal figure commencing at any given point, and terminating at the same. In tracing this circuitous route it is necessary to measure the lengths of the sides, and also the angles between them, before a plan of it can be laid down. Referring to the lines in Fig. 7116, let a survey be required of the area contained between the stream and the road. Set out the lines A B, B C, C D, ... N A; measure the lengths of the sides and the angles, and it will be evident that the figure may be laid down on paper. The method of procedure in the field is as follows;—Starting from a point at which observations can be made on surrounding objects, as at A, set out the lines A *a*, A O, A B, and plant the theodolite at A. Clamp the limb and vernier-plates at 360°, or zero, and turn the whole instrument round until the magnetic needle lies over the north and south line N S, and clamp it firm in that position. Release the vernier-plate and bring the telescope to bear consecutively on A *a*, A O, A H, A P, A E, and lastly on A B, clamping the vernier-plate each time; having carefully entered at station A all the angles made by the above lines with the magnetic meridian, and having both clamps firmly fixed, the last reading

being with the telescope bearing on A B, remove the instrument to B, plant it at this station, and carefully level it. Release only the clamp-screw of the limb; the vernier-plate must not be disturbed, or the operation will have to be repeated.

7116.

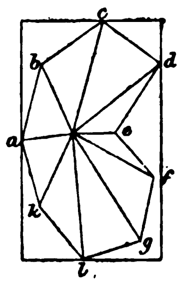


Now turn the theodolite bodily round, so that the telescope reversed may bear on A, where a man must be left to hold a flag-pole, clamp the limb, and perfect the contact by means of the slow-motion screw S, and examine the readings of the verniers to see that no disturbance has taken place. A few words are now required with regard to the telescope being reversed. This operation places the horizontal limb and the verniers in the same position, with regard to the magnetic meridian, as that which is occupied at A. If, for instance, at A, the bearing of A B was 31° east of north, by doing as directed the theodolite is similarly placed at B, with the same vernier still pointing 31° east of north, and it is the second vernier, lying diametrically opposite, which now points towards A, and reading on the limb $31° + 180° = 211°$. Release the upper or vernier plate, and turn the telescope round to bear on C; clamp the instrument; read both verniers to get the mean of the bearing B C, which is here 96° 5'; now move the theodolite to C, release the horizontal limb, turn the instrument bodily round to B, clamp and release the vernier-plate, turn the telescope round to D, and clamp. By reading the angle the bearing of C D is obtained, which here is 30° 5'; proceed in the same manner at D, E . . . M, O, at which station, when the back-sight is fixed on M, and the telescope reversed towards A, the verniers should give exactly the same angle as was read off at A, with the telescope bearing on O; and this because O A marks the same angles with the meridian N' S'' that A O does with the magnetic meridian N S. If it be so, then the angles have been correctly taken; if otherwise, then their difference is the error committed. Besides taking at A the bearings of A O and A B, those of A *a*, A H, A P, and A E have been also taken. The bearing of A *a* was taken in order to get in the bit of road beyond the bridge, and to show the position of such road in connection with the lands surveyed; and also in case the survey has to be extended in that direction, as then the instrument would be planted at station *a*, and the back-sight fixed on A, in the same manner as directions have just been given for doing at B, C, D. With regard to the bearings of A H and A E, they are taken here only as checks on the work as it proceeds, for it will be observed that E A makes with the meridian N'' S'' at E the same angle west, that A E at A makes east with N S. These observations have equal weight with regard to the bearings A H and H A. The points H and E have been selected at the other end of the survey, and of which full view could be had from A; otherwise any other points, as F, G, or I, would have been taken if convenient. As regards the various bearings on P, let it be observed that these are checks, for if there is any error, these bearings will not intersect at P, when the work is plotted and the bearings A P, E P, G P, are laid off with the protractor. It is necessary that they be taken on some object in a commanding situation, such as may be seen at least at several points. Judgment is required in selecting such points, as they may often be very useful to chain upon in order to fill in interior work, as fences and buildings. On an extensive traverse this should particularly be kept in sight, as it prevents the necessity of having again recourse to the instrument when filling in. It is to be observed that in Fig. 7116 the stations in the road are all shown as in the centre of it; but this has merely been done to avoid confusion, and not to be followed as a rule. On the

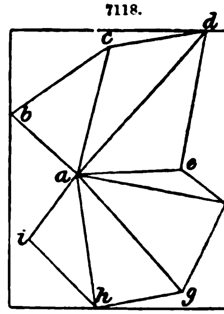
contrary, it is to be avoided, inasmuch as all these stations require to be carefully marked, either by driving a picket or making some other mark, which is often very awkward to do in the centre of a road. The stations should therefore be placed somewhere near the road-side, but so that the theodolite can be readily set up. The traverse being thus set out, the sides are chained and the offsets taken in the usual manner. With regard to the magnetic needle, care is required lest it is affected by any local attraction; but by following the above method there will be opportunity to observe this at each succeeding station, as the back angles with the meridian are equal to the forward angles.

There is a considerable advantage in taking from the starting point A such bearings as A H and A E, for it subdivides the larger polygon into smaller ones, as in Fig. 7116, where the figure A B, B C . . . O A is subdivided by the above bearings into the smaller polygons A B, B C . . . E A, and A B, B C . . . H A; we are thus enabled to check the work as it proceeds; for in the same manner the three angles of a triangle are equal to two right angles, and the four angles of a four-sided figure are equal to four right angles; so all the interior angles of a polygon are equal to twice as many right angles, minus four, as the figure has sides. The proof of this may be seen in Figs. 7117, 7118. In the first, let the polygon *a b*, *b c* . . . *k o*, be divided into triangles, by drawing lines from each angle of the polygon to any point in the interior of the figure; then because the three angles of a triangle are equal to two right angles, we shall have twice as many right angles as the figure has sides, for there is a triangle for every side, and all the angles formed by the lines intersecting are together equal to four right angles; subtracting these, we shall have for remainder twice as many right angles, less four, as the figure has sides.

7117.



7118.

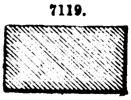


In Fig. 7118 from any point *a* in the polygon draw lines to each of the remaining angles, as *a c*, *a d*. The polygon will thus be divided into as many triangles as the figure has sides, minus two, for there is only one triangle for each of the two sides *a b*, *b c*, and *a i*, *i k*; and one triangle for each of the remaining. In any case, therefore, multiplying 180° by the number of sides of the polygon, minus two, will give the interior angles of the polygon. Thus in Fig. 7116, where the polygon has thirteen sides, all the interior angles will be equal to $180° \times 11$, or to $90° \times 26 = 360°$. In the same manner the angles of the polygon A B, B C . . . E A $= 180° \times 3$, because the figure has five sides; and the angles of the polyglon A B, B C . . . H A $= 180° \times 6$, the figure having eight sides. The rules often given to find the interior angles of the polygon lead rather to confusion than anything else. The simplest way is to carry a small semicircular protractor, about 3 in. in diameter in the pocket, and plot the bearings in the field-work, merely writing in the degrees and minutes inside the several angles; or even to sketch in two lines, at right angles to each other, for the magnetic meridian and the east-west line, and sketch in the bearings as the work proceeds. Many surveyors sketch or roughly plot a traverse in a field-book, quarto size, but it is very inconvenient in wet, stormy weather, when time presses and the work must go on.

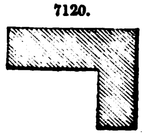
Plotting and Plan Drawing.—In plotting a survey, or drawing the plan, a good deal of latitude is permitted to the draughtsman with respect to the manner in which he may fill in the details. The first point to decide is whether the plan is to be coloured or not. As a rule, plans should always be coloured, not merely for the sake of appearance, but for the purpose of displaying the characteristic features of the ground. It will be assumed in future that the plans for which we are about to indicate the proper methods of delineating their respective features will be coloured.

The commonest and yet the most important objects represented in plans, are buildings, including ordinary dwelling-houses, churches, chapels, outhouses, and many others of a similar description. Some of these have a particular outline, but they may be all filled in, as represented, in their different ways. It is frequently not of any importance to ascertain the exact shape or size of a house situated near to the main line of a survey, and all that is necessary is to determine its actual position. In this case it is represented by one of the two forms Figs. 7119, 7120, and it may be filled in according to one of three methods. Although the plan be coloured, yet a house or building may be what is termed hatched, or crossed over with lines drawn in Indian ink, as in the figure. If this method is employed, it should always be borne in mind that the lines should be drawn to a constant angle in every building delineated in the plan, or otherwise a most unpleasing effect will be produced by the want of uniformity. The angle may be either 60° or 45°. These are the most convenient angles to use, as the ordinary set squares are made to them. It is, nevertheless, preferable to colour the buildings in a plan, and the conventional colour is carmine.

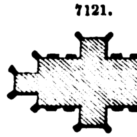
7119.



7120.



7121.

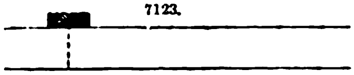


7122.

Buildings may also be coloured with a flat wash of Indian ink, but, strictly speaking, this wash should be confined to the outhouses in connection with dwelling-houses, and indicates an inferior

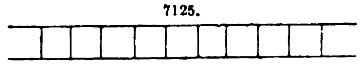
description of structure. This distinction is maintained in the coloured plans of the Ordnance maps, which are drawn to the enlarged scale of $\frac{1}{2500}$, and is one which is of considerable importance in surveys of land where it is in contemplation to run a line of railway or lay out other large works. As a familiar example, take a farm-house, with its adjoining barns and outhouses. The dwelling-house itself is to be coloured carmine or lake, and the surrounding smaller erections in Indian ink. Churches and chapels are represented in the same manner, but the former have the outline shown in Fig. 7121, and the latter that in Fig. 7122. Windmills, water-mills, forges, glass and iron works, have also their characteristic conventional sign. Roads of various degrees of importance as routes of intercommunication are tinted burnt sienna, or, what answers better, a mixture of that colour and yellow ochre. A bright yellow, such as gamboge or King's yellow, should never be employed. It should be carefully borne in mind that a plan should never be coloured, but tinted. In delineating roads they may be divided into two classes—fenced and unfenced roads. The former are represented by hard lines, and the latter by dotted ones. A turnpike-road is shown in Fig. 7123, a cross or second-rate road in Fig. 7124, and a railroad in Fig. 7125. Sometimes a railroad is shown by a single thick black line, and it is always thus represented in the parliamentary and contract plans of any proposed line. On the Ordnance map it is shown as indicated in Fig. 7125, and it is preferable so to delineate it, as a thick black line is not in itself sufficiently distinctive. There is one more distinction which it is necessary to observe in the case of roads, and that is, when they are raised over or sunk under the natural surface of the ground, in other words, when they are embanked, and when they are excavated. A

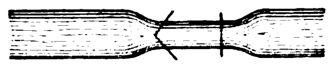
7123.



7124.

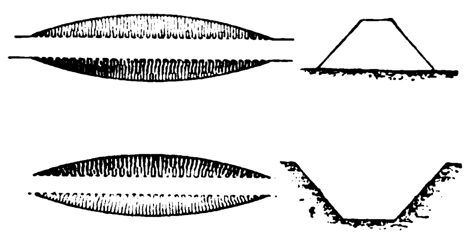
7125.





7126.

7126*.

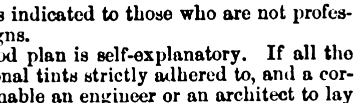


plan and transverse section of both are shown in Fig. 7126*, which need no further description. It is scarcely necessary to make any remark respecting rivers, lakes, streams, ponds, and other examples of pieces of water, as blue is their proper tint, with a stronger shade near the banks. Instead of using a wash, the same effect may be produced by lines drawn with Prussian blue, but for the reasons already given the tinting is to be preferred. A portion of a canal or river rendered navigable, where a lock is placed, is represented in Fig. 7126. When it will not interfere with the other lettering upon a plan, it is always as well to write the word lock alongside its representation, as it is thus indicated to those who are not professional men, and may not be acquainted with conventional signs.

It is undeniable that to a professional eye at least a good plan is self-explanatory. If all the objects are properly and accurately delineated, the conventional tints strictly adhered to, and a correctly divided scale appended, nothing more is required to enable an engineer or an architect to lay it before him, and comprehend the whole of it at a glance. Accuracy and clearness are the two essential points to be borne in mind in the preparation, not merely of plans, but of drawings of any description whatever. It is of the greatest importance to define with all possible precision the various kinds of boundaries or lines of demarcation existing between different portions of land and territory. There are a very large number of boundaries and a corresponding number of conventional signs for individually representing them. For instance, there are parish boundaries, county, union, hundreds, wards, boroughs, liberties, and some others which are pretty nearly extinct at the present day.

The two boundaries most commonly occurring on plans are those of parishes and counties. They are represented respectively in Figs. 7127, 7128, and consist simply of a succession of short straight lines separated by spaces. It is easy to perceive that if carelessly executed, they might readily be mistaken for each other, and it is not an unusual circumstance for such to be the case. To avoid the occurrence of this it is only necessary to bear in mind that the lines delineating the parish boundary are smaller and thinner than those representing that of a county; and, what is of still greater importance, they are equal in length to the spaces between them. In addition to properly delineating these boundaries, it is advisable to write alongside them their names, but this should only be done once, on some convenient part of the map or plan. Boroughs are usually divided into two separate classes, under the heads of parliamentary and municipal boroughs. The former has its limits defined by small circles, Fig. 7127, and the latter by black dots, Fig. 7128. It sometimes happens that the same limits may be the boundaries of several different descriptions of properties. Thus a fence, for instance, might be the boundary of a parish, a parliamentary, and a municipal borough. In such a case the delineation of it would consist of a joint-

7127. 7128.

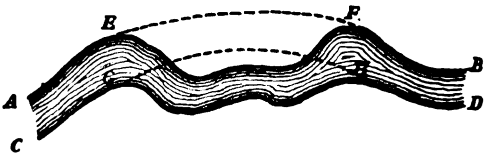


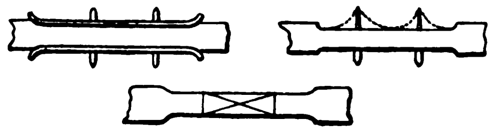
7129.

representation of all three, as shown in Fig. 7129. So also for a combination of any other boundaries which are plotted after a similar fashion.

Unless otherwise stated on the plan, a hard line denotes a fence or a boundary between the two portions of land upon each side of it. Ordinary fences are represented by a hard line, and when of stone, a distinction may be made by drawing the latter in red. Some judgment must be exercised in using this colour for the purpose. If the plan has other red lines upon it showing proposed alterations of the existing features of the ground, such as alterations of the course of rivers, or of the direction of roads, which are always represented by red lines, it will be better to draw the stone fences in black, and thus avoid all chance of confusion. In Fig. 7130, suppose A B C D to represent the existing course of a river which it is intended to alter and improve by getting rid of the two elbows in it. This would be effected by making the new cut E F G H shown by the dotted lines. On the plan these dotted lines would be drawn in red, and sometimes the portion of ground included within them is coloured with a light wash of the same tint. Occasionally the lines are simply dotted, as in Fig. 7130, but it is preferable to draw them in red, as the distinction between the existing features of the ground and those resulting from the proposed alteration is at once apparent. The manner in which existing works will be affected by those proposed to be executed cannot be shown too clearly on the plan. The usual method of indicating the crossing of a road or stream by a bridge, is to draw a couple of hard lines across them, and leave the space between them which equals the width of the bridge, uncoloured. At the same time, each bridge, according to its type of construction and the material of which it is built, has its proper conventional delineation. Stone and timber bridges are drawn nearly alike; the former being distinguished by being drawn in red lines, or, if the scale of the plan admit of it, the walls may be lightly tinted of the same colour. A wooden bridge is also distinguished from a stone as well as from an iron one, by having lines drawn closely together across its width to represent planking. The correct manner of plotting an iron bridge is given in Fig. 7131 to the left. A suspension bridge is shown to the right of the same figure, the distinguishing characteristics, namely the suspension chains, are too clearly defined to allow of any room for doubt respecting the individuality of the structure. A drawbridge is shown in the centre of Fig. 7131.

7130.



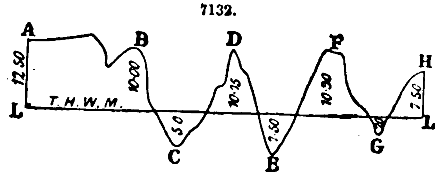


7131.

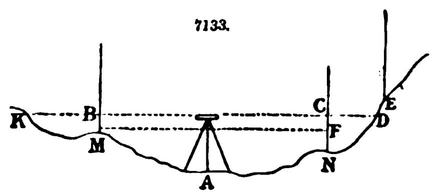
Enlarging and Reducing Plans.—Of the several methods by which these operations can be effected, that of squares is the most accurate. This consists in covering the original drawing with a complete network of squares, and the copy with a similar network, having the sides proportioned so as to suit the different sizes of the two drawings. Proportional compasses are also used for the same purpose, and so are the Pantograph and Eidograph. Enlarging a plan is a more difficult operation than the reduction of one. The large plans of the Ordnance Survey drawn on a scale of $\frac{1}{2500}$ were reduced to the scale of 6 in. to a mile by photography. The details of the plans so reduced are afterwards traced on copper plates on which the stations have been previously plotted by the lengths of the sides of the triangles. The only method of reproducing any plan or section with complete fidelity is to plot it over again upon the scale which is required.

Levelling.—Surveying may be regarded as the horizontal, and levelling as the vertical measurement of ground, and, in the majority of instances, they are closely connected together. Equally important as the horizontal delineation of the ground is its correct vertical representation. Levelling may therefore be regarded as that art by which we arrive at an exact knowledge of the superficial configuration of the earth above and below any fixed datum. Thus, for example, if the datum assumed is Trinity high-water mark, the height of any point above, or the depth below it, is usually recorded in feet, and decimals of a foot. This is shown in Fig. 7132, where L L represents the line of high-water mark, and the heights of the several points A B C D are marked in feet, and decimals of a foot. Upon the whole, the best instrument for an engineer or surveyor is the Dumpy, or Gravatt's level. The simplest case of levelling that can possibly occur, is that in which it is

7132.



7133.

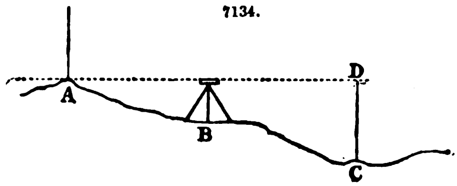


required to ascertain the difference of level between any two points which can both be seen without shifting the instrument. Supposing the two points to be sufficiently near to be within the optical powers of the telescope, the possibility of ascertaining their difference of level by one setting up of the instrument will altogether depend upon the amount of that difference. Fig. 7133 will render this clear. Let it be required to determine the difference of level between the points M and N.

Set up the instrument at A, and take a reading on the staff at B, which put equal to 2·10 ft. Now, if the distance of N from M be not greater than what can be seen by the telescope, turn the level round on its axis, and take a reading on the staff at C, which make equal to 5·35. Bearing in mind that both B C and M F are horizontal lines, it is evident that the difference of level between the two points M and N is equal to the height F N. But F N = C N − C F and C F = B M. Consequently F N = C N − B M. But by the readings C N = 5·35 and B M = 2·10; therefore F N or the difference of level between the two points M and N = 5·35 − 2·10 = 3·25 ft.

It is easy to perceive that when the instrument is once set up and adjusted for levelling, its range of action in that one position is limited. For instance, referring to the diagram with the instrument planted or set up at A, it cannot read a staff placed on any point of ground above the dotted line D K. If it were therefore required to ascertain the difference between the points M and E, it could not be done with the instrument placed at A. The instrument would either have to be shifted between the points N and E, after taking the first reading at B and C, or placed upon some higher ground, which would enable readings to be taken directly upon the staff placed first at one point and then at the other. This will be more fully explained when we treat of ascertaining the difference of level between several points, or what is usually termed making a section. The readings are classed under one or other of two titles. They are either back-sights or fore-sights. They have not necessarily any reference to the direction in which the section is taken, but the back-sight is always taken before the fore-sight. In some instances, where intermediate sights are taken, each fore-sight becomes a back-sight to the next fore-sight, as will be explained in its proper place. In the diagram, B M is the back-sight, and C M the fore-sight, and from them the following universal rule is deduced. When the fore-sight or the sum of the fore-sights exceeds the back-sight or the sum of the back-sights, there is a fall from the first point to the last, and when the contrary occurs, there is a rise between the same points. In this instance, C N is greater than B M, and consequently there is a fall, or the point N is lower than the point M. The maximum difference of level, either rise or fall, that can be observed at one setting up of the instrument cannot exceed the total length of the staff. Let us suppose in Fig. 7134 that the reading taken at A is exactly at the zero of the staff, and that the reading at D is exactly at the top line of the graduations of the staff, then the difference of level between A C equals the precise length of the staff. If the point C be situated lower down, it is evident that the top of the staff would drop below the dotted line, and no reading could be observed. It is barely within the limits of possibility that, in practice, two readings would be obtained of which the one would equal zero, and the other the exact length of the staff, but the illustration is given to show the maximum difference of level that it is just possible to ascertain without shifting the instrument. Besides this, it points out that the setting up of the level is not a matter of hazard or mere chance, but should be regulated according to the position of the points of which the level is required. The more experienced and skilful a surveyor is in selecting the spot where to plant his instrument, the more rapidly will he get over the ground. By setting up the instrument in the most favourable spots he obtains a greater range of the staff, and thus diminishes the number of times of planting the level which would otherwise be necessary. Nor is this all. The chances of errors creeping in are in direct proportion to the number of times the level is shifted between any two points, so that by reducing this number to a minimum, the chances of error are also minimized.

7134.



It has been assumed in the three diagrams to which we have drawn attention that the dotted lines were horizontal, and so they will be when the instrument is correctly adjusted. The correct horizontal of the dotted line A D in Fig. 7134, or the similar ones in the other two diagrams, depends, other things being equal, upon the correct adjustment of the line of collimation. See Surveying Instruments.

Having briefly described the simplest case that can occur in levelling, which consists of taking merely a couple of readings of the staff, we once more pass on to the general case. This includes the ascertaining of the difference of level between any number of points. These relative heights may or may not be referred to any one common point as a datum. As a rule, they are so referred, although it is not absolutely necessary, either for accurate levelling or accurate plotting. Supposing therefore all the points which indicate the respective levels of the different parts of the ground to be joined by lines, the result is a section, or a representation of the vertical inequalities of the ground. In the section relating to surveying, regarded in connection with the horizontal delineation of land, attention was directed to the fact that the field-book might be kept in one or two different ways. So it is with levelling. The level-book, as it is now termed, may be also kept, and is kept in a slightly different manner. Military engineers, moreover, keep their level-books on a system differing somewhat from that of civil engineers. There is no actual difference, so far as principle is concerned, in any of the methods employed, but, nevertheless, when a level-book, reduced according to one system, is put into the hands of a person accustomed only to another, he finds some difficulty in deciphering it and plotting a section from it.

One page of the level-book is usually occupied with the columns, and the other reserved for remarks and such memoranda as it may be necessary to note during the taking of the levels in the field. Sometimes the disposition of the columns is altered. Thus, for instance, the columns of rise and fall are in some books put between those of back and fore sights, but this is a point of no importance whatever, as it is easy to fall in with the arrangement of the columns, and reduce the book with equal facility after a little practice, in whatever manner the relative columns may be disposed. Let us now examine a little into the field-book or level-book given in our example. The datum to which the levels are reduced is assumed to be equal to 100·00, a very ordinary and

convenient assumption. The reason of adopting that figure will be explained as we proceed. It is supposed therefore that the first reading is taken on the heel-post of a gate, which is termed a bench-mark, and usually denoted by the letters B. M. This is entered in the column of back-sights as 11·56. At a distance of 100 ft. from the B. M. another reading is taken upon the staff, and entered in the column of fore-sights as 4·69. Let it be supposed now that it is required to move or shift the instrument beyond the distance of 100 ft., so as to get a fresh back-sight upon the staff at the same place where a fore-sight was previously taken. The important point now is to be sure that the staff-man, in turning the back of the staff round, does not alter its position with respect to the spot it is held on. Inattention to this particular will completely vitiate the whole section, and render accurate results impossible. Returning to the field-book, the next back-sight will be entered as 6·40, the next fore-sight as 10·72, and so on until the section is finished. The distances are entered in their proper column, opposite the places where the corresponding readings of the staff are taken.

The simplest description of level-book, or that in which the minimum number of columns is required, is represented in the annexed form in Table II.;—

TABLE II.

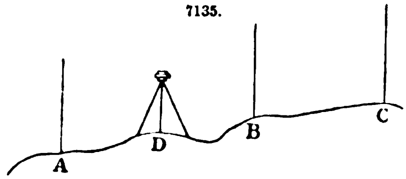
Back-sight.	Fore-sight.	Rise.	Fall.	Reduced Level.	Distances.	Remarks.
11·56	..	..	..	100·00	0	B. M. on heel-post of gate.
..	4·69	6·87	..	106·87	100	
6·40	10·72	..	4·32	102·55	200	
3·15	7·19	..	4·04	98·50	300	In front of house.
7·25	2·40	4·85	..	103·36	400	
8·10	5·16	2·94	..	106·30	500	
7·03	5·23	1·80	..	108·10	560	
11·44	2·91	8·53	..	116·63	600	
5·11	13·24	..	8·13	108·50	645	On coping of wall of chapel.
8·19	4·65	3·54	..	112·04	700	
7·81	11·12	..	3·31	108·73	780	
0·60	9·48	..	8·88	99·85	800	
5·64	7·08	..	1·44	98·41	900	On edge of stream.
12·70	3·33	9·37	..	107·78	1000	
4·15	9·80	..	5·65	102·13	1100	
99·13	97·00	37·90	35·77	2·13		
97·00		35·77				
2·13		2·13				

Reduction of Levels.—Having entered all the readings, and finished what is called the field-work, the next step is the reduction of the book, or the arithmetical checking of the operation. This check must not be confounded with that which is known as checking the levels, which will be referred to in its place. The first thing to be done is to subtract the lesser readings from the greater, and enter the results in the respective columns of rise and fall, remembering that when the fore-sight is greater than the back-sight, there is a fall, and a rise in the reverse case. This being accomplished, the whole columns of back and fore sights should be added up, and the lesser subtracted from the greater, the difference being entered as shown in the example we have selected. Now let the columns of the rise and fall be treated in a similar manner, and if the arithmetic be correctly performed, the difference will be exactly equal to that already obtained in the former columns. It is just possible that there might be a compensating error of the same amount introduced in these two processes, which would consequently not be apparent, and thus the check would be invalid. A third column is therefore required, which would render this balancing error apparent. This is found under the head of reduced levels. By adding to the datum the successive rises and subtracting the falls, the differences between the last reduced level and that datum should equal the difference already obtained. When the three operations check, it may be relied upon that the arithmetic is correct, and the book reduced accurately. It must be borne in mind that all this must be done before any of the section is plotted, or otherwise it would have to be drawn over again if any errors were detected. In some level-books there is a column for intermediate sights, but it will be seen presently that it is not necessary. An intermediate sight is one taken in the first instance after a back-sight, and is in fact a fore-sight, but it differs from a fore-sight, properly so called, inasmuch as the instrument is not shifted, and no second reading is taken at the same place, to serve as a back-sight for the next forward reading.

It has been mentioned that intermediate sights might be regarded in the light of fore-sights, provided they were treated as back-sights for the next reading. In the terms fore-sight and back-sight, it must be borne in mind that they have not necessarily any connection with the position of the telescope at the time of reading them. To some extent they are, in this respect, a misnomer, and are only strictly correct when one sight is taken on one side of the instrument, and the other with the telescope reversed on its bearings. The field-book employed when a column is given to the intermediate readings is reduced in the same manner as that described for the other form. In Fig. 7135 suppose the instrument be set up as represented in the diagram, and a reading taken

off the staff at A, and entered as 13·20 in the column of back-sights. If another reading be taken at B, and the instrument be not shifted until after another reading has also been taken at C, then the reading at B is an intermediate sight, and is entered in the proper column as 5·40. The reading at C is the fore-sight proper, and is entered in its proper column as 8·20. An intermediate sight is therefore, as in fact its name implies, a reading taken anywhere between the readings of the back and fore sight. It follows, as a corollary from the above, that when the instrument is set up, the first sight taken can never be an intermediate, nor can it ever be the last reading before the shifting of the instrument. A glance at the diagram will indicate that the position of the staff, with respect to the instrument, has nothing whatever to do with the character of the reading taken on it.

7135.



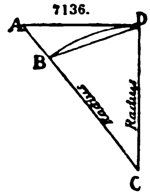
Thus it is evident that, speaking generally, any number of readings might be taken between the point A and the point D, where the instrument is placed. All these would be intermediate sights, and entered in the level-book accordingly. The entries in the level-book have therefore no connection with the actual positions of the staff and instrument at the time the sights were taken. It is true that in order to plot the section, the distances at which the sights are taken are noted, but this gives merely the total distance from a starting point, and, by subtraction, that between any two sights. What is to be observed is, that there is no clue to the exact position of the instrument to be deduced from the level-book. There is, however, an approximate clue readily obtainable by inspection. For instance, on referring to the copy of the field-book, it will be seen that after the fore-sight 8·20 was entered there is a new back-sight of 4·30. The position of the staff at the former reading was 100 ft. from the starting point. The position of it at the reading of the next fore-sight is 6·50, and its distance 200. Consequently, as the level was shifted after reading 8·20, it must have been set up somewhere between 100 and 200 ft. from the starting point. The reading 10·70 of the intermediate sight is of no use in determining the position of the instrument, for although its distance is entered as 150, yet the level might have been set up at 130 or 170 without affecting the character of the sight. Referring to Fig. 7135, the reading 10·70 might have been taken between the points A and D, or D and C.

There are various other descriptions of level-books used, but we shall only mention one more. It is very similar to that already given, only it has a separate column for the height of instrument. Sometimes this column is substituted for that of intermediate. Those who are practical levellers are aware that it is impossible to get a sight very close to the instrument by looking in the ordinary manner through the telescope. When the object becomes situated very close to the object-glass, the focus cannot be adjusted for distinct vision. Under these circumstances the usual plan is to run the eye along the outside of the telescope, and note the reading accordingly. When the staff can be seen through the telescope, although not sufficiently clear to distinguish the figures or marks on it, a reading may be obtained by causing the staff-man to run his finger up and down the staff until it comes within the range of the cross wires, when the reading can be afterwards ascertained by the naked eye. Let us now examine into the object of making a column in the field-book for recording the height of the instrument, and find out the advantages of so doing. It is nothing more than taking a reading at the point where the level is set up. The height of the instrument is obtained by measuring accurately the height of the centre of either the object or eye glass from the ground and entering it in the column. The distance of the instrument is also recorded, so that not only is there an additional reading obtained by this method, but the position of the instrument is also accurately determined. This latter detail is sometimes of importance in checking levels when mistakes have been made, and bench-marks are rather far apart. If it is known that the instrument was set up at such and such a spot, it is easy to tell by the eye that it would have been impossible to obtain certain readings of the staff placed at another known point. It may be here observed that if a level is suspected of being out of adjustment, the errors that would arise in consequence, may be neutralized by placing the instrument exactly half-way between the back and fore sights. In fact, wherever great accuracy is required, this precaution is invariably taken, although the instrument may be in perfect adjustment. One reason for pursuing this course is that it renders unnecessary the taking into account the questions of refraction and the influence of the sphericity of the earth upon the readings. In ordinary levelling these questions are disregarded, but it sometimes becomes necessary to take them into account. The errors that, if neglected, they would give rise to in levelling operations, on a scale similar to that carried into execution by the officers of the Ordnance Department in the great trigonometrical survey of the kingdom, dwindle down into insignificance when the object in view is simply the laying out of the route of a railway or canal. So far as these errors and their causes are concerned, the climate and the condition of the atmosphere possess considerable influence. Anyone who has levelled on a very hot day, with a bright glaring sun shining, must have noticed the peculiar appearance the readings sometimes assume, and how difficult it is to adjust the focus of the eye-piece so as to be sure to have no parallax at different distances. That it is by no means an uncommon affair for even experienced professional men to be out in their levels under certain circumstances, is demonstrated by the Suez Canal. The levels of the two seas which it now unites were ascertained by several parties of engineers, who all disagreed in their reports. Some maintained that the difference of level was very considerable—so considerable as to be fatal to the union of the waters, while others said the difference was inappreciable, which has since proved to be the case.

Correction for Curvature.—The two errors incidental to levelling are those arising from the curvature or sphericity of the surface of the earth, and from the peculiar nature of the medium or atmosphere by which it is surrounded. The error resulting from the curvature of the surface of the earth arises from the fact that horizontal lines are not level lines. A strictly level line is

one in which all the points are equidistant from the centre of the earth. From this definition it will be at once perceived that a horizonal line cannot be a level line, since the point at which it is a tangent to the earth's surface must be nearer to the centre of the earth than any other point in its direction. So much is readily comprehensible, but for the illustration and proof of the error we must refer to Fig. 7136. In the diagram let B D be any portion of the surface of the earth, A D a horizontal line representing the line of sight of the telescope of the level, and tangential to the surface of the earth at D, and C the centre of the earth. The points D and B are clearly on the same level, whereas B and A are not. But A appears to be the level of the point B, as seen by the observer at D. Consequently the difference between the true and apparent level of the point B is the distance A B. This distance is therefore the measure of the error due to the sphericity of the earth's surface, commonly called the error due to curvature. It is also called the correction for curvature.

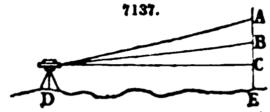
7136.



It remains to calculate mathematically the value of A B, which is an unknown quantity, in terms of those which are known. By the proposition, A D is the distance, or length of the sight, practically equal to the arc B D and the chord B D; C B and C D are radii of the earth. From the 47th prop. of the first book of Euclid we have $AC^2 = AD^2 + CD^2$. But $AC = (AB + BC)$, consequently $(AB + BC)^2 = AD^2 + DC^2$. But $BC = DC$; therefore $(AB + DC)^2 = AD^2 + DC^2$. Expanding, we obtain $(AB^2 + 2(AB \times DC) + DC^2) = AD^2 + DC^2$, and equating, the formula becomes $AB^2 + 2\,AB \times DC = AD^2$. The value of A B by this equation would be represented by $AB^2 + AB = \frac{AD^2}{2 \times DC}$, which is a quadratic equation of the form $x^2 + ax = \frac{b}{c}$. The formula is, however, very much simplified by making an assumption very common in mathematical demonstrations. A glance at the diagram will point out that A B must always be relatively very small compared with the radius of the earth B C. The square of A B will be still smaller, and it may therefore be neglected in the calculation, and the equation becomes $AB = \frac{AD^2}{2 \times DC}$. Or putting D for the diameter of the earth, $AB = \frac{AD^2}{2 \times D}$. Bearing in mind that the denominator of the fraction is a constant, the correction for curvature is proportional to the square of the distance, a law which is applicable to numerous other instances besides that under consideration. A simple rule for the difference of level is that the correction for the curvature in feet is equal to two-thirds of the square of the distance in miles. This rule is readily deduced from the formula $AB = \frac{AD^2}{2 \times D}$, for expressing both the numerator and denominator in feet, and taking A D equal to one mile, $AB = \frac{5280}{7916}$ = nearly $\frac{2}{3}$.

Correction for Refraction.—The next cause of error will now be investigated. It will be seen hereafter that as they tend in some degree to neutralize each other's effects, they will have to be combined in the total amount of correction to be applied, but for the present, for the sake of simplicity, each will be treated of separately. This second cause of error is known as that of refraction, and is due to the varying density of the atmosphere surrounding the earth. By the laws of optics a ray of light passing from one medium into another of a different specific gravity or density, is bent or refracted in one or another direction, according as the density of the medium into which it enters is greater or less than that which it has left. Consequently a ray of light passing from a higher to a lower level will be refracted in a curve concave to the surface of the earth, since it passes from a rarer into a denser stratum, the density of the atmospheric strata increasing towards the earth's surface. But according also to optical laws, an object is seen in the same direction as that in which the rays of light strike on the retina, and therefore the line of vision will be a tangent to the curve of refraction, and an apparent displacement of the exact level or height of the object will be the result. As this tangent or visual line will be above the curve, the effect of refraction is to raise the object above its true level, and its connection will therefore be of an opposite character to that for refraction. This will be seen from Fig. 7137, where A C, representing the correction for curvature, equals A B in Fig. 7136, and A B equals that for refraction. Calling the former negative and the latter positive, the total correction equals $AB - AC = BC$. Owing to the uncertain conditions attending the atmosphere, the error due to refraction is not capable of being so accurately determined as that due to the sphericity of the earth, and cannot be expressed by any recognized formula. It may, however, be fairly considered to have an average value of about one-sixth of the former error, and from this assumption a formula for its value may be found. The correction for curvature in feet has, in fact, been found to be equal $\frac{2\,D^2}{3}$, to calling D the distance in miles. That for refraction is equal to $D^2 (\frac{2}{3} \times \frac{1}{6}) = \frac{D^2}{9}$. But since the former is negative and the latter positive, or, for the sake of simplicity and to avoid a negative result, these signs may be reversed. The total correction represented by B C in Fig. 7137 will be equal to the difference of these two fractions. Putting C to represent the total correction for both curvature and refraction, we obtain $C = D^2 (\frac{2}{3} - \frac{1}{9}) = \frac{15\,D^2}{27} = 0 \cdot 55\,D^2$.

7137.



The following is therefore the simple rule for ascertaining the total correction for both causes of

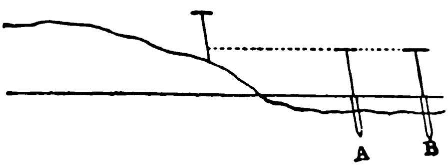
error; "Square the distance in miles, multiply the result by 0·55, and the product will be the total correction in feet and decimals of a foot."

It has been stated that whenever practicable it is advisable to set up the instrument as nearly as possible midway between the back and fore sights. By adopting this precaution the errors due to curvature and refraction are annihilated, since the sum of them will be the same, but the combined effects will neutralize each other.

Boning.—Boning is a rough description of levelling, which is often performed by foremen or gangers in road and railway making. An experienced man, if given a couple of levels at the commencement and termination of a given gradient, will bone the intermediate levels with very great accuracy. Boning is performed with boning rods, which exactly resemble T squares, in the following manner:—

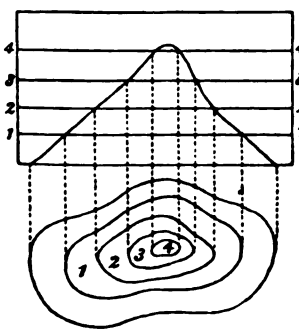
Let A and B, Fig. 7138, be two stakes driven to a certain depth, and according to a given inclination; if on both of these stakes boning rods, of exactly equal lengths, be held perfectly upright, these will be parallel to the incline, and if a third rod be carried along the intended slope, the top of it will be in a line with the top of the other two, if the incline be correct; if it is above, there will be more to cut away; and if it is below, the excavation will have been made too deep; this method is certainly but approximate, quite sufficient to guide the excavators for a time.

7138.

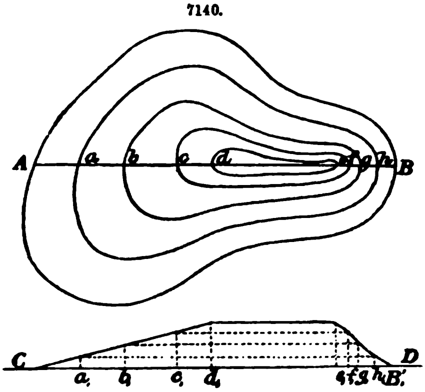


Contours and Hill Shading.—When the ground is horizontal, the signs which we have given are quite sufficient to represent the country by the outline and relative position of every object; but when the ground is no longer level, new signs become indispensable to complete the plan, so as to make it convey exact ideas of the hills, valleys, ravines, and other undulations of the surface. A plan should therefore fulfil these two conditions; first, represent the ground so as to enable us to ascertain the relative height of the different points, and to judge of the nature of the slopes; second, give a figure of the ground that will immediately afford an idea of its character. The first condition requires geometrical methods, whilst the second can only be obtained by combinations of shades. The geometrical method consists in supposing the ground intersected by horizontal planes; the projections of these intersections, or horizontal contours, are then transferred to the drawing at their reduced size. Procure a stone somewhat resembling a hill, as may frequently be found; fix it with clay to the bottom of a box provided with a plug-hole, and sufficiently large to leave a space free between the stone and its case. Fill the box with water stained with Indian ink, and let it off, by means of the plug, about a quarter of an inch in depth, at several times, allowing sufficient intervals for the fluid to stain the stone in that plane, 4, 3, 2, 1, it has fallen to at the last abstraction. These stains will present a series of horizontal lines or contours, 4, 3, 2, 1, all round the surface of the stone, as shown in Fig. 7139; and if we examine the stone thus prepared, looking down upon the top, we shall see that the steepness and the flexures of its sides will be accurately marked by these contours, which might be said to form a scale of relative steepness.

7139.



7140.



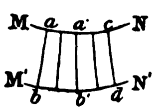
7141.

The level of the water constitutes a horizontal plane, therefore those contours are the intersections of the stone by parallel horizontal planes. What is said of a stone may be said of a hill, or of any surface, and those horizontal contours will give us a geometrical representation of the ground. But if we suppose the horizontal planes of section to be equidistant, we can at once, being given the altitude of one point and the equidistance, find the altitude of another point. The inclination of the slopes may also be found by dividing this equidistance by the perpendicular, common to two consecutive contours. A profile of the ground in any direction can also be obtained; the section of the ground along the direction A B, for instance, is found, Figs. 7140, 7141, by carrying on any line C D, distances C a', C b', respectively equal to A a, A b, and drawing through those points a', b', perpendiculars representing the altitude of the contours a, b, c; the lines that connect the extremities of those perpendiculars figure the section. Elevations may also be drawn by the usual method of geometry.

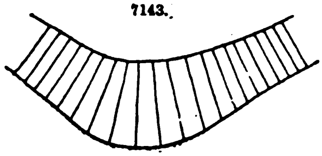
By diminishing the equidistance, the description of the undulations can become very accurate, and almost exact. It will therefore vary with the scale of the plan, and the nature of the country surveyed; and the larger the scale, the smaller the equidistance. In the Irish survey of 6 in. to the mile, it was 50 ft. for cultivated parts, and 100 ft. for mountainous and barren districts. In France, as a rule, the ratio between the equidistance and the denominator of the scale is constant, and $= \frac{1}{2000}$, a great advantage is therefore gained, since at whatever scale a plan is made, the same inclination will always be represented by contours equally distant. At the scale $\frac{1}{10000}$, the sections are thus 5 mètres apart; at $\frac{1}{20000}$, 10 mètres, and so on. In exceptional cases only is this ratio altered. Thus, for the most level plains of Champagne, the Ordnance Survey adopted the ratio of $\frac{1}{4000}$, giving an equidistance of 5 mètres, at the scale $\frac{1}{20000}$.

This method of representing the ground answers the first condition which a plan should fulfil, and is now adopted everywhere for engineering purposes. The second condition, as we stated, can only be obtained by combinations of shade; and if the conventions we adopt in order to gain this object are made to depend upon the principle of the horizontal contours, we shall obtain the very important result of combining accuracy with expression. This effect of shade might be produced by adapting the equidistance to the scale and to the nature of the ground, so as to have contours close enough to give a shading. If, on the other hand, we insert a sufficient number of lines between a few contours determined by levelling, the ground is not faithfully represented; the surface between two such contours has not always a uniform slope, and the space between two contours of the drawing would be a mean surface either enveloping or intersecting the real one. The execution would be tedious and difficult. Hence methods have been devised, some having regard to expression only, others combining expression with accuracy. We may classify them under three heads, the French system, the German system, and the English system. In the French system the hachures are traced perpendicular to the contours, so that the equidistance compared with the length of these hachures will at once give the ratio of the slope. The original contours must therefore be preserved on the plan, and the proper effect of light and shade is produced as follows;—$M N$, $M' N'$, Fig. 7142, being the contours given, the hachures $a\,b$, $c\,d$ are drawn at a distance, $a\,c = a\,b$; the square they form is then divided into two equal parts by $a'\,b'$, and the rectangles $a\,b'$, $a'\,d$ arising therefrom are again divided into two.

7142.

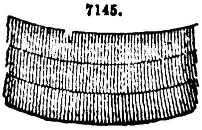


7143.

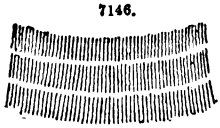


7144.

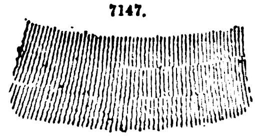
7145.



7146.



7147.



By this process the hachures are at a distance from each other = ¼ of their length, and in the practice the etching is thus expeditiously done. Should not the contours be parallel, Fig. 7143, the hachures are drawn so as to meet them at right angles. This, however, becomes difficult when the contours are far apart, and beginners will find it more easy to pencil intermediate contours in sufficient numbers to have them nearly parallel, and the hachures are afterwards kept at the proper interval. When the distance between the contours is very small, it becomes impossible to draw three hachures in the square; they are then made thicker and kept at equal intervals, as in Fig. 7144. The effect of shade they produce will thus harmonize with those of less rapid slopes. This should be done as soon as the distance of the contours is less than about $\frac{1}{10}$ of an inch, and the smaller this distance the thicker the etched lines should be. In order to preserve on the drawing the traces of the original contours, which are always useful to find altitudes, the hachures of a slice should not be the continuation of those above A, but should be made to correspond to the intervals of the slice immediately above; and to avoid the bad effect B produced by lighter spots, they should be exactly terminated at the contour C, Figs. 7139 to 7141. In order to secure a uniformity of shade for all plans, scales of thickness or diapasons have been adopted. In the diapason of the French Ordnance Map, Fig. 7145, the ratio of black to white is equal to the tangent of the slope multiplied by $\frac{3}{2}$. For a slope of 45 degrees the proportion of black to white is thus 3 : 2. All slopes steeper than 45 degrees are represented as escarpments. The French system, we have said, combines accuracy with expression, but is not expeditious. It is the best for engraved maps. In the German system the hachures are also perpendicular to the normal contours, with or without reference to their equidistance.

In the system of Lehmann, Fig. 7146, no regard is paid to the equidistance, and the slopes are measured by the angle they form with the horizon. The diapason of Lehmann gives, therefore,

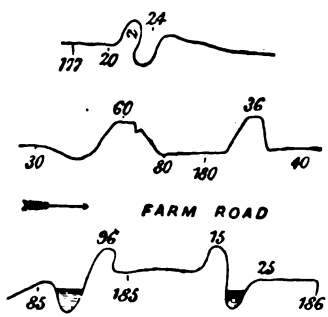
the length and thickness of the hachures from 5 to 6 degrees up to 45 degrees. The latter slope, being impracticable to armies, he represents by absolute black. The ratio of black to white is equal to the ratio of the angle of a slope to its supplement to 45 degrees. Thus, for the slope of 35 degrees, the thickness of the hachures is so regulated as to give a tint in which the black is to the white as 35 : 10, or 7 : 2. In this method the features of the ground are strongly marked, but the tints are too dark, and it is often difficult to read the small writing and see the details. In other German diapasons the maximum of shade is taken for 60 degrees, but these methods requiring the measurement of every angle, are too long in practice. English systems are of two kinds; the horizontal style and the vertical style, both of which had till lately only expression in view. The vertical style, Fig. 7147, has only been employed to obtain expression, and it is not more accurate than the above style, and requires more time. The horizontal style, with some modifications, has been exclusively adopted in all the military schools of the Government since 1867.

Thus, with the scale of 6 in. to the mile, the dotted contours are shown at the vertical distances of 25 ft. for all slopes below 5°, 50 ft. for all slopes from 5° to 10°, 100 ft. for all slopes from 10° to 20°, 200 ft. for all slopes from 20° to 40°.

With the scale of 3 in. to the mile, these distances would respectively be 50, 100, 200, 400 ft. This method is far less simple than the French system, since in the same drawing the distance between the contours is liable to vary. There will, however, always be two defects in all the varieties of horizontal style. The roads, in hilly ground, deviate but little from the horizontal plane, and are not easily distinguished from the horizontal strokes to which they remain parallel. Again, the extreme strokes at the summit and base of a hill cannot be melted into the soft appearance of natural shade. Besides these three systems, there are other methods of hill shading. Brushing with Indian ink is one of them; but it is not susceptible of great accuracy, and is only employed for rough sketches.

To give more accentuation to the features, oblique light has been had recourse to, but it is impossible to represent the real steepness of a slope, since the same slope may be placed in a thousand different positions as regards the direction of light; hence the same slope is differently shaded; it must also be observed that the horizontal surface having to be shaded, the effect is no longer natural.

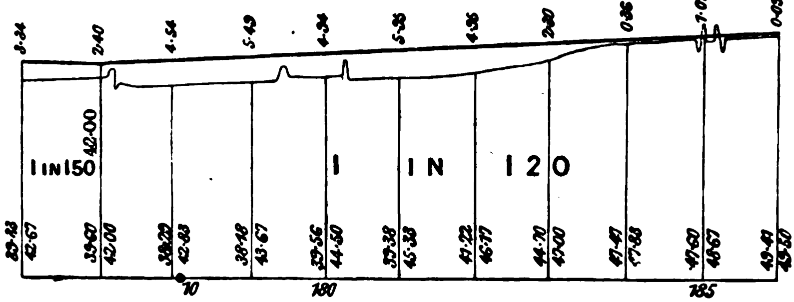
Fig. 7148.

Back Staff.	Fore Staff.	Rise.	Fall.	Reduced Levels.	Distance in chains.	Remarks.
				39·35		
5·00	5·02	..	0·02	39·33	176	
	4·75	0·27	..	39·60	177	
	6·50	..	1·75	37·85	·60	
	6·06	0·44	..	38·29	178	
	5·82	0·24	..	38·53	·10	
	6·17	..	0·35	38·18	179	
6·30	6·00	0·30	..	38·48	·30	
	4·80	1·20	..	39·68	·80	
	4·92	..	0·12	39·56	180	
	5·50	..	0·58	38·98	·40	
	5·10	0·40	..	39·38	181	
	3·26	1·84	..	41·22	182	
9·29	5·81	3·48	..	44·70	183	
	3·04	2·77	..	47·47	184	
	2·70	0·34	..	47·81	·85	
	5·50	..	2·80	45·01	·87	Bed of stream, 2 in. water.
	2·91	2·59	..	47·60	185	Peg in Farm road.
7·32	7·60	..	0·28	47·32	·06	Centre of Farm road.
	9·54	..	1·94	45·38	·19	Bed of stream, 3 in. water.
	6·50	3·04	..	48·42	·25	
	5·51	0·99	..	49·41	186	
27·91	17·85	17·90	7·84	10·06	Rise.	

Plotting the Section.—In plotting a section, the first care is to obtain a perfectly straight datum line. This is best obtained by stretching a fine silk thread from one point to the other, and making points along it at such distances as can be conveniently connected by a straight-edge. The vertical distances at which the rises and falls occur, as shown in the level-book in Fig. 7148, are plotted as represented in Fig. 7149. The gradients, if the section be intended for a road or railway, are then laid down. They are obtained by taking the difference of heights between the two ordinates at the two extremities, and dividing it into the distance or length of the gradient. Thus, in the example in Fig. 7149, there is a gradient of 1 in 120 laid down. The thick black vertical line or ordinate is marked 42·00, and supposing the ordinates to be 100 ft. apart, we have at the end of a horizontal distance of 600 ft. a rise of 5 ft., and if we look at the ordinate at that distance, it will be seen that its vertical height is 47·00. The difference between the reduced level of the ground and that of the gradient height, or the formation surface of the road or railway, gives the height of the embankment or depth of cutting, as the case may be. Although in the section in Fig. 7149 the ordinates are shown at regular distances of 100 ft., yet they must be erected at every point which

corresponds with a distance registered in the column of distances in the level-book, Fig. 7148. Having plotted all the heights on the ordinates, the points are joined, and the section of the ground

7149.



thus obtained. In commencing to lay down the gradients, there are always some fixed points which guide the engineer in his selection, as has been already observed in Railway Engineering, in treating of the choice of route for a line of railway.

In conclusion, it may be remarked. that however excellent may be the maps available, yet if a really accurate survey is required, the only reliable method is to have the ground surveyed and plotted to the actual scale desirable in the particular instance. A corrected plan, that is, one which has the omissions inserted, the superfluities erased, and the necessary alterations introduced, is rarely to be depended upon. In the majority of cases it gives absolutely less trouble to survey the ground, than to correct an imperfect plan of it already existing. Moreover, a corrected plan never gives that thorough satisfaction and confidence which an engineer feels in one which he has made himself.

See Geodesy. Railway Engineering.

Works upon Surveying;—Adams (G.), 'Geometrical and Graphical Essays,' 8vo, 1813. Ainslie (J.), 'Treatise on Land Surveying,' 8vo and 4to, 1849. Bourns (C.), 'Principles and Practice of Surveying,' 8vo, 1867. Smith (J. A.), 'Treatise on Land Surveying,' crown 8vo, 1869. Nesbit's 'Practical Land-Surveyor,' 8vo, 1870. Merrett (H. S.), 'Land and Engineering Surveying,' royal 8vo, 1871. Gillespie (W. M.), 'Treatise on Land Surveying,' 8vo, New York, 1872. Lieut.-Gen. Frome, 'Outline of a Trigonometrical Survey,' 8vo, 1873. Haskoll (W. D.), 'Practice of Engineering Field Work,' 8vo.

SURVEYING INSTRUMENTS. Fr., *Instruments de l'arpenteur;* Ger., *Messinstrumente.*

All surveying instruments are intended for measuring horizontal, vertical, or angular distances. Of the many varieties of these which have been used from time to time, it is our intention to describe only those which experience has proved to be the best adapted for modern practice, both at home and abroad.

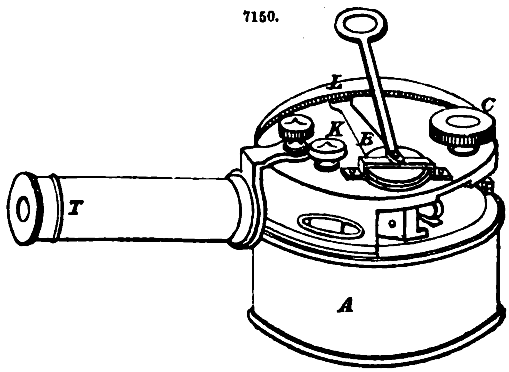
The Chain.—A partial description of this simple but indispensable instrument has been given in Surveying and Levelling, but there are a few points with reference to it which belong strictly to the present article. The correct length of a chain should be that from out to out, that is, from the outside of one handle to the outside of the other. Oval-shaped rings are far preferable to round ones, and there are always in the best made chains three of these rings between each link. At a distance of every ten links on each side of the centre of the chain there are similarly marked pieces of brass, so that the brass, as it is termed, at forty links from the one end corresponds with that at forty links from the other. These mark respectively forty or sixty links, according to the end of the chain whence the counting is commenced. At the centre of the chain the brass is perfectly plain, with no nicks or cuts in it. To every chain ten pins or arrows are attached, pointed at one extremity, and having an eye at the other. In order to test a chain, it should be stretched out straight, and a weight of about 30 lbs. hung at one end, the other being made fast. On removing the weight the chain should return to its original length, or if a new one, very nearly so.

Tapes.—Measuring tapes are made either of linen, or of linen interwoven with fine brass wire, and called metallic tapes. It is stated that the metallic tapes stretch more than the linen ones, but this is doubtful. Tapes are apt to fray at the edges, especially if they are slightly too large for the box, an occurrence which sometimes happens when new tapes are put into old boxes, or when they are carelessly wound up. A good box will last out many tapes. In winding up a tape, it should be allowed to run through pretty closely between the middle and fore finger. If this be not done, it is liable to get twisted or doubled up inside the box; and if in drawing it out, it be forcibly pulled out, it gets very much damaged. The proper plan in such a case is to unscrew the winding knob, and take the tape out of the box through the aperture at the centre. Tapes are also made of steel, but require careful handling, as they are liable to snap.

Instruments for Measuring Angles by Reflection.—Of these the box sextant and the prismatic compass are the most useful. The former instrument is represented in Fig. 7150, and forms, when shut up, a box, having a depth of $1\frac{1}{2}$ in. and a diameter of about 3 in. When observations are being made, it is held in the hand, and requires no other support. It will read, by the aid of a vernier, angles to a single minute, and when once thoroughly adjusted, does not become easily disarranged. In using the sextant, the lid or cover A is first unscrewed, and then screwed on to the bottom of the box, forming a handle with which to hold the instrument. Many sextants are provided with a telescope T, which is then drawn out, and the dark glasses having been lowered by means of two small levers, the instrument is ready for observation. B is an index arm, having at its extremity

a vernier, of which thirty divisions coincide with twenty-nine of the divisions upon the graduated limb L. As the divided spaces upon the limb each denote thirty minutes, or half a degree, the angles observed are read off by means of the vernier to a single minute. The index is moved by turning the milled head C, which acts upon a rack and pinion within the box. To the index arm is attached a mirror, called the index glass, which moves with the index arm, and is firmly fixed upon it, so as to have its plane accurately perpendicular to the plane in which the motion of the index arm takes place, and which is called the plane of the instrument. This plane is identical with the plane of the face of the instrument, or of the graduated limb L. In the line of sight of the telescope is placed a second glass, called the horizon glass, having only half its surface silvered, which must be so adjusted that its plane may be perpendicular to the plane of the instrument, and parallel to the plane of the index glass when the index is at zero. The instrument is provided with two dark glasses, which can be raised or lowered by means of two little levers, so as to be interposed, when necessary, between the mirrors and any object too bright to be otherwise conveniently observed, as the sun. The eye end of the telescope is also furnished with a dark glass. In order to adjust the horizon glass of the instrument, first put the dark glass in front of the eye end of the telescope. Look through it at the sun and move the index arm B backwards and forwards through a small angle, on either side of zero, until the reflected image of the sun pass over the image seen directly through the horizon glass. If the one image exactly cover the other, so as to constitute in reality but one image, the horizon glass is in adjustment, that is, it is perpendicular to the plane of the instrument. But if this should not be the case the key K must be unscrewed from the place it occupies, and applied to a screw on the top of the instrument, which acts upon the horizon glass, and turned until the adjustment is effected.

7150.

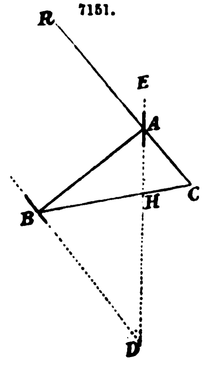


To ascertain the index error, after making the adjustment just described, make the reflected image of the lower limb of the sun to coincide with the direct image of the upper limb, and take the reading of the vernier, and suppose it to be in front of the zero mark. Then move the index bar back beyond the zero mark of the divided limb L until the reflected image of upper limb of the sun coincides with the direct image of its lower limb. If the zero of the vernier on the index arm be now exactly as far behind the zero mark on the divided limb L, as it was previously in front of it when making the other observation, so that the two readings are identical in value, but of opposite sign, the instrument is in perfect adjustment. But if not, half the difference of the two readings is the amount of the error, and is called the index error, being a constant error, for all angles observed by the instrument, of excess, if the first reading be the greatest, and of defect, if the second reading on the arc of excess be the greatest. In the former case the true angle will be found by subtracting the index error from the reading of the instrument at every observation, and in the latter by adding it.

This error can be removed by applying the key k to a screw in the side of the instrument, and turning it gently till both readings are alike, each being made equal to half the sum of the two readings first obtained. When this adjustment is perfected, if the zeros of the vernier and limb are made exactly to coincide, the reflected and direct image of the sun will exactly coincide, so as to form but one perfect orb, and the reflected and direct image of any line, sufficiently distant to be unaffected by parallax, as the distant horizon, or the top or end of a wall more than a mile off, will coincide so as to form one unbroken line.

To obtain the angle subtended by two objects situated nearly or quite in the same vertical plane, hold the instrument in the right hand, and bring down the reflected image of the upper object by turning the milled head C till it exactly coincides with the direct image of the lower object, and the reading of the instrument will give the angle between the two objects.

7151.



To obtain the angle subtended by two objects nearly in the same horizontal plane, hold the sextant in the left hand, and bring the reflected image of the right-hand object into coincidence with the direct image of the left-hand object.

The box sextant is essentially a reflecting one, and in consequence its principle is founded upon the same data which govern all instruments of a similar character. The results of all reflecting instruments are based upon the fact that the deviation of a ray of light after reflection at the index glass and that called the horizon glass, is double the angle of inclination between the two glasses. This will be rendered clear by a reference to the diagram, Fig. 7151. Let A represent the index glass of a sextant, which is moved by the index arm as required, and B the horizon glass which is fixed permanently in a plane perpendicular to that of the instrument. The angle of inclination between the two glasses in any one given position will therefore equal in the diagram the angle A D B. If we imagine R to represent a ray of light impinging upon the mirror A, it will be reflected from A to B, and by the laws of optics the angle of incidence R A E will equal the angle of reflection B A D. On arriving at B, the second mirror, the ray of light will

be again reflected in the direction B C, making, according to the same law, the angle A B F equal the angle C B D. The total deviation of the ray of light is measured by the angle A C B, and by the conditions of the problem this must be equal to twice the angle A D B, or that between the index or horizon glasses.

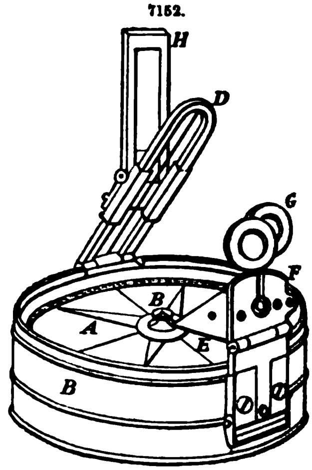
In the two triangles A H C, B H D, the angle A H C equals the angle B H D, and consequently the remaining angles H A C, H C A of the one triangle equal the remaining angles H B D, H D B of the other. But the angle H B D, being the angle of reflection, equals the angle A B F, which is the corresponding angle of incidence. This latter angle being the exterior angle of the triangle A B D, equals the two interior and opposite angles H D B, B A D; therefore the angle H B D equals the angles H D B, B A D. From above the angles H A C, H C A = angles H B D + H D B; therefore substituting for H B D its value of the angles H D B + B A D, we have the angles H A C + H C A = angles B A D + 2 H D B. But the angle B A D, the angle of reflection, equals angle R A E, the angle of incidence, which is equal to angle H A C; therefore the remaining angle H C A or A C B equals 2 H D B, or the angle of deviation of the ray equals twice the angle between the glasses. This angle is practically equal to that subtended by the object and its image at the eye of the observer. The difference between it and the actual theoretical angle is usually called the parallax of the instrument, which may be altogether eliminated by properly handling it. When the eye of the observer, the centre of the index glass and the object, form three points in the same straight line, this error becomes reduced to zero. In order to obviate the necessity for first registering an observation and then doubling it to obtain the angle required, the divisions on the arc or limb are marked double what they really represent, so that the correct angle is read off by the vernier at once. In reading the angle, care should be taken to bring the microscope perpendicularly over the vernier, or else the true reading will not be obtained. A reading taken on the skew will not be accurate.

The sextant is not applicable to objects which do not lie approximately in the same horizontal or the same vertical plane. Strictly speaking, the two objects, the angle between which is required, ought to be situated exactly in the same plane, but a little departure from this rule is of no practical inconvenience. The observer, even if his eye be no guide to him, can always tell in taking the angle whether this condition is fulfilled or not, as he will be obliged to incline the sextant to one side or the other, in order to obtain the necessary overlapping of the objects. This is a point that requires attention, for angles observed between two objects situated widely out of the same horizontal or vertical plane, are incorrect, and a survey so conducted will not close properly. We have known considerable errors arise from ignorance and neglect of this necessary precaution. This is one of the points in which a sextant is inferior to a theodolite. Should it, however, be absolutely indispensable for want of another instrument to find with the sextant the horizontal angle between two objects which are not situated in the same horizontal plane, the actual oblique angle may be observed, and the true horizontal angle deduced from it by spherical trigonometry. This is a case that rarely occurs in practice, and one that should be sedulously avoided.

The pocket sextant offers a ready method of laying off right angles, for by setting the vernier to 90°, it really becomes to all intents and purposes an optical square. This latter instrument is a small sextant with the mirrors fixed at the angle of 45°, and incapable of recording any other. The mirrors of a sextant after some use get very dirty. The best way to clean them is by the use of a small light brush. A telescope, as already observed, is frequently attached to the instrument, but it is of very little practical use, and only complicates its manipulation. When once in thorough adjustment a sextant, with proper care, will last so for a very long period.

The Prismatic Compass.—As this instrument can be used either in the hand or with a tripod stand, and with it angles can be observed with great rapidity and tolerable accuracy, it is especially valuable to the military surveyor. It is also well adapted for filling in the details of a large trigonometrical survey, and was used for this purpose by those engaged in making the English Ordnance surveys. It is represented in Fig. 7152, and forms a small and compact instrument. Referring to the figure, A is a compass card usually divided to every $20'$, or third part of a degree. Underneath the card is a magnetic needle, turning upon the agate centre B. The vibrations of the card when playing freely can be checked by touching a small spring in the side of the box. The sight-vane D has a fine thread stretched across it, which should bisect the point under observation. The sight-vane is mounted on a hinge-joint, which enables it to be turned down flat in the box when it is out of use. E is a prism attached to a plate sliding in a socket, so that it can be raised or lowered as required. It is also mounted on a hinge-joint, and can be turned down into the box. The prism is attached to a plate F, which projects beyond the prism, and has a narrow slit, forming the sight through which the vision is directed when making an observation. On looking through this slit, and raising or lowering the prism in its socket, distinct vision of the divisions on the compass card immediately under the sight-vane is soon obtained, and these divisions, seen through the prism, all appear, as each is successively brought into coincidence with the thread of the sight-vane by turning the instrument round, as continuations of the thread, which is seen directly through the part of the slit that projects beyond the prism.

7152.



The method of using the instrument is as follows;—The sight-vane D and the prism E, being turned up upon their hinge-joints, as represented in Fig. 7152, the instrument is held as nearly

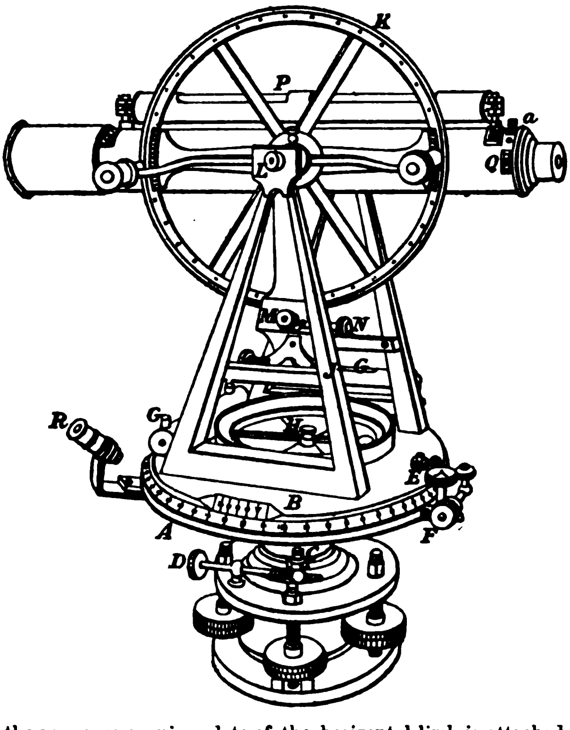
horizontal as possible, or, if it be used with a tripod stand, set as nearly horizontal as can be done by moving the legs of the stand, so that the card may play freely. The prism is then raised in its socket until the divisions upon the card are seen distinctly through the prism, and the instrument turned round until the object to be observed is seen through the portion of the slit projecting beyond the prism in exact coincidence with the thread of the sight-vane. The card is then brought to rest by touching the spring; and the reading at the division upon the card, which appears in coincidence with the prolongation of the thread, gives the magnetic azimuth of the object observed, or the angle which a straight line, drawn from the eye to the object, makes with the magnetic meridian. The magnetic azimuth of a second object being obtained in the same manner, the difference between these two azimuths is the angle subtended by the objects at the place of the eye, and is, moreover, independent of any error in the azimuths, arising from the slit in the prism not being diametrically opposite to the thread of the sight-vane.

By taking the variation of the compass, as it is termed, that is, the difference between the magnetic and the true north, from the Nautical Almanack for the year, the true meridian line can always be obtained. Although the prismatic compass is a convenient instrument for filling in details, it must never be employed where accuracy is required. Owing to numerous causes which affect observations made by the aid of a magnetic needle, the angles cannot be relied upon to nearer than half a degree. In Fig. 7152 there are two dark glasses at G, which may be made to turn over the sloping side of the prism, and are useful when observing under a strong glare of the sun. A mirror is shown at H, which can be attached to the sight-vane D, or removed at pleasure. Its use is to reflect an object when it is much below or above the level of the observer. A stop is provided to throw the needle off its centre when it is not in use.

The Circumferenter is a compass mounted upon a stand, with sights, and is now only used for mining surveys.

The Theodolite.—The modern form of this important instrument is represented in Fig. 7153. It may be considered as consisting of three parts; the parallel plates with adjusting screws fitting on to the staff-head; the horizontal limb, for measuring the horizontal angles; and the vertical limb, for measuring the vertical angles, or angles of elevation.

7153.



The horizontal limb is composed of two circular plates, A and B, which fit accurately one upon the other. The lower plate projects beyond the other, and its projecting edge is sloped off, or chamfered, as it is called, and graduated at every half degree. The upper plate is called the vernier-plate, and has portions of its edge chamfered off, so as to form with the chamfered edge of the lower plate continued portions of the same conical surface. These chamfered portions of the upper plate are graduated to form the verniers, by which the limb is subdivided to single minutes. The 5-in. transit theodolite, Fig. 7153, has two such verniers 180° apart. The lower plate of the vertical limb is attached to a conical axis passing through the upper parallel plate, and terminating in a ball fitting in a socket upon the lower parallel plate. This axis is, however, hollowed to receive a similar conical axis ground accurately to fit it, so that the axis of the two cones may be exactly coincident or parallel to one another. To the internal axis the upper, or vernier, plate of the horizontal limb is attached, and thus, while the whole limb can be moved through any horizontal angle desired, the upper plate only can also be moved through any desired angle, when the lower plate is fixed by means of a clamping screw, which tightens the collar C. D is a slow-motion or tangent screw, which moves the whole limb through a small space, to adjust it more perfectly, after tightening the collar C by the clamping screw E. There is also a clamping screw for fixing the upper, or vernier, plate to the lower plate, and a tangent-screw F, for giving the vernier-plate a slow motion upon the lower plate, when so clamped. Two spirit levels G are placed upon the horizontal limb, at right angles to each other, and a compass H is also placed upon it in the centre, between the supports J, J, for the vertical limb.

The vertical limb K is divided upon one side into four quadrants, each way from 0° to 90°, and subdivided by the verniers, which are fixed to the axis of the telescope, to single minutes. Upon the other side are marked the number of links to be deducted from each chain, for various angles of inclination, in order to reduce the distances, as measured along ground rising or falling at these

angles, to the corresponding horizontal distances. The axis L of this limb must rest, in a position truly parallel to the horizontal limb, upon the supports J, J, so as to be horizontal when the horizontal limb is set truly level, and the plane of the limb K should be accurately perpendicular to its axis. On top of the telescope is fixed the bubble P. The horizontal axis L can be fixed by a clamping screw M, and the vertical limb can then be moved through a small space by a slow-motion screw N.

Adjustments.—Before commencing observations with this instrument, the following adjustments must be attended to;—

Adjustments of the telescope, which comprise the adjustment for parallax and for collimation. Adjustment of the horizontal limb and of the vertical limb.

When the image of the object viewed, formed by the object-glass, either falls short of, or beyond the place of the cross wires, the error arising from this cause is called *parallax*. The existence of parallax is determined by moving the eye about when looking through the telescope, observing whether the cross wires change their position, and are flittering and undefined.

To correct this error, first adjust the eye-piece, by means of the movable eye-piece tube, till the cross wire is clearly defined, and sharply marked against any white object.

Then by moving the milled-headed screw at the side of the telescope, the internal tube is thrust outwards or drawn inwards, until the proper focus is obtained according to the distance of the object, and the object can be clearly seen, and the intersection of the wires, clearly and sharply defined, before it. The existence of parallax is very inconvenient, and, where disregarded, has frequently been productive of serious error. It will not always be found sufficient to set the eye-glass first and the object-glass afterwards. The setting of the object-glass, by introducing more distant rays of light, will affect the focus of the eye-glass, and produce parallax or indistinctness of the wires, when there was none before; the eye-piece must, in this case, be adjusted again.

Generally, when once set for the day, there is no occasion for altering the eye-glass, but the object-glass will of course have to be altered at every change of distance of the object.

In adjusting the instrument, the parallax should be first corrected, and then the error of collimation.

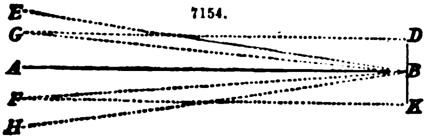
Adjustment for Collimation.—To collimate a transit theodolite, set the cross wires on some very distinct distant object by means of the tangent-screw F. Now unclamp the vertical circle, and lift the horizontal axis, carrying the telescope with it out of its bearings in the supports J, J. Replace it in its bearings with the ends reversed, so that the telescope is upside down. If the cross wires now coincide exactly with the same point as when the telescope was in its original position, the line of collimation is perpendicular to the horizontal axis, and the instrument is in adjustment in that particular respect. But if this coincidence does not obtain, one half of the deviation must be corrected by moving the cross wires by means of the horizontal adjusting screws attached to the diaphragm, and the other half by means of the tangent-screw F. Reverse the telescope again, and repeat the operation until the adjustment is accomplished. The telescope may be reversed for the purpose of effecting this adjustment in another manner. It may be turned over on its horizontal axis, and the horizontal limb revolved through an angle of 180°. To adjust the line of collimation in a vertical direction the same operation is to be carried out, but the vertical screws *a*, in Fig. 7153, must be used instead of the horizontal.

Adjustment of the Horizontal and Vertical Limbs.—Set the instrument up as accurately as possible by the eye, by moving the legs of the stand. Tighten the collar C by the clamping screw, and, unclamping the vernier-plate, turn it round till the telescope is over two of the parallel plate screws. Bring the vertical circle carefully to zero by turning the tangent-screw N. Turn the vernier-plate half round, bringing the telescope again over the same pair of the parallel plate screws, and if the bubble of the level be not in the centre of its run, bring it to the centre, half-way by turning the parallel plate screws over which it is placed, and half-way by turning the tangent-screw N. Repeat this operation till the bubble remains accurately in the centre of its run in both positions of the telescope; and then turning the vernier-plate round till the telescope is over the other pair of parallel plate screws, bring the bubble again to the centre of its run by turning these screws. The bubble will now retain its position while the vernier-plate is turned completely round, showing that the internal azimuthal axis about which it turns is truly vertical. The bubbles of the levels on the vernier-plate being now, therefore, brought to the centres of their tubes, will be adjusted to show that the internal azimuthal axis is vertical. Now, having clamped the vernier-plate, loosen the collar C by loosening the clamping screw, and move the whole instrument slowly round upon the external azimuthal axis, and if the bubble of the level above the telescope maintains its position during a complete revolution, the external azimuthal axis is truly parallel with the internal, and both are vertical at the same time; but if the bubble does not maintain its position, it shows that the two parts of the axis have been inaccurately ground, and the fault can only be remedied by the instrument maker. When the horizontal limb is in adjustment, that is, when the bubbles of two levels on the vernier-plate remain in the centre of their run, during all positions of the revolution of either the vernier-plate or the whole instrument around the vertical axis, the bubble above the telescope should be in the centre of its run when the vertical arc or circle is set to zero. Should this not be the case, there is an index error which must be allowed for in all observations made with the vertical limb.

The bubble tubes are frequently mounted with capstan-headed screws at both ends, but in both theodolites and levels of the most modern make, they are mounted with a hinge at one end and a single screw at the other, as shown in Fig. 7156. This is by far the best method of mounting them, as they retain their adjustments more permanently. There is this difference to be remarked respecting their nature, and it is necessary to be certain that in the latter plan it can never happen that the hinged end should ever require lowering. Fig. 7154 will render our meaning clear. Since the bubble always runs to the highest end, there is no necessity of raising or lowering more than one end of the tube, provided the other is free to pivot upon a hinge, but not to have any vertical motion. In Fig. 7154 let A B represent the correct position of the bubble tube when the instrument is properly set up and levelled.

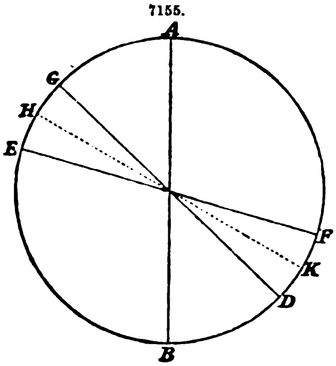
Let A be the screw end, and B the hinged extremity, which it must be borne in mind cannot by construction be raised or lowered. Suppose the level tube to be deranged, and the screw end to occupy the position shown by the dotted line G B, it is evident that it may be restored to a horizontal position either by lowering the end G to the point A or raising B to the point D, the line G D being parallel to A B, and therefore horizontal. But as the end B cannot be raised, the only alternative is to lower G. But suppose the instrument is badly constructed, so that, after lowering the movable end as much as possible, that is, screwing it down as far as the screw will go, it still remains too high. Then there is no remedy but that of sending the instrument to the maker to have the bubble tube taken off and remounted. Referring to the diagram for an illustration, suppose the end A to be deranged so as to occupy the position shown at E, and that after screwing it down as far as possible it can only be brought to G, the bubble tube will then occupy the position shown by the dotted line G B, and will be always out of level until remounted. A similar contingency is represented by the dotted lines F B, H B on the lower side of the line A B, on the supposition that the movable end at A has been lowered by derangement instead of raised. In the extreme case we have selected, it is supposed that the end A which was at H could not be raised higher than F, and as B could not be lowered to K, the position of the bubble tube would be represented by the dotted line F B. In purchasing a theodolite or a level with the bubble tubes mounted on a hinge, if when the instrument is set up and levelled the movable or screw end of the tube is raised much above its bearings, it should be rejected, as the tubes will never be steady under the least rough usage. When all the parts of a theodolite or level are fresh from the hands of the maker, all the adjusting screws should be nearly home, and the instrument will then be in what is termed permanent adjustment.

7154.



The next point to be considered with respect to a theodolite is the position of the verniers. These are two in number, placed opposite one another, that is, at a distance of 180° apart on the divided limb. The verniers are sometimes fixed at the proper distance apart in the making of the instrument, and at other times are movable, so as to be capable of accurate adjustment when required. The object of having two verniers is to ensure great accuracy in the observations. When this is needed, the angles are read off by both verniers and the mean taken, which tends to reduce any small error that might otherwise occur. In the diagram in Fig. 7155, let A B represent the normal position of the verniers of a theodolite, that is, when they are both at zero, A being one vernier, and B the other. Suppose a reading is taken with the vernier B only, the angle read being equal to B D. But suppose also in the reading of the angle an error is made in excess equal to D F, which would be equivalent to reading the angle B F instead of B D. One reading only being taken with one vernier, the error remains. But if when the angle B F is read by error, the angle A C be read with the other vernier, and the mean of the two readings A C and B F be taken, the error becomes reduced to D K or half D F. Instead of supposing the readings to be wrongly taken, if we imagine trifling errors to exist in the verniers themselves, the same line of reasoning holds good. Trifling errors do exist in the verniers, and it is for the purpose of nullifying them that they are both used. In ordinary practice it is not necessary to use both verniers, and the surveyor should always use the same vernier during the same series of operations, making a slight scratch on one of the verniers so as to be able to distinguish it from the other. When the verniers of a theodolite are fixed by construction, if they do not each coincide with the zero of the divided lower plate to within three or four minutes, the instrument is faulty. Having completed our remarks on the levels and verniers, there is still one more important consideration to attend to. It is the vertical position of the supports J, J, in Fig. 7153. In some instruments, always in those of a large size, there is a separate adjustment for this purpose, but in many there is none, the supports being set vertical by the maker. To ascertain this, set up the instrument accurately level, direct the intersection of the cross wires to some well-defined vertical line, such as the quoin of a building, and move the telescope up and down. If the intersection of the wires coincide during the whole motion of the telescope with the edge of the quoin the construction is good, if not, bad, and the fault can only be remedied by the maker. As a piece of practical advice; always turn the instrument in the same direction either backwards or forwards, but not indifferently backwards and forwards. The reason for this is, that there is always some lubricating substance present between the axial bearings, and if the instrument is constantly turned in the same direction, this is always maintained in a smooth and even state. But when the rotation is backwards and forwards it gets rubbed up, and interferes with the evenness of the movements.

7155.

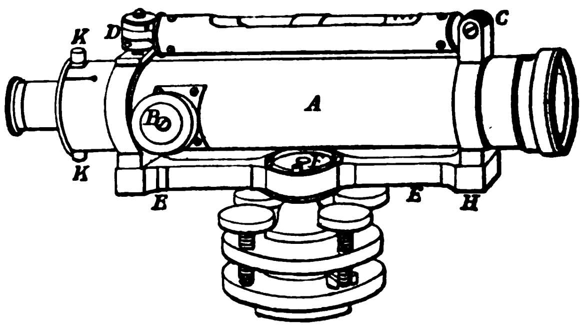


Everest's Theodolite.—In Everest's theodolite, a number of which were made for use in India, instead of the upper parallel plate there are three diverging arms, with a vertical foot screw supporting the end of each. In setting up a theodolite over any station, a plumb-bob is hung from a small hook which is placed in the upper part of the legs, and is situated exactly under the vertical axis of the instrument. On referring to Fig. 7153 it will be seen that the microscope R for reading the divisions on the horizontal limb is mounted on a little bracket, which slides in a groove in the lower part of the rim of the limb. This is a complete mistake in the construction of the instrument, and it is astonishing that the makers have not altered the arrangement. As the microscope is only

needed to read the vernier, and that portion of the horizontal limb corresponding to it, the proper place for it is on the vernier-plate. As the vernier-plate revolved it would carry the microscope with it, and it would always be where it was wanted. In the position in Fig. 7153 it is not only in the way, but when shifted along its groove it is very liable to disturb the level of the instrument. It may be useful for those who are in possession of cradle theodolites to know that they can be converted into transit theodolites.

Levelling Instruments.—The three best-known levels are the Y, Troughton's, and Gravatt's, or the Dumpy level. Of these the last is so universally used by engineers that a description and illustration of it will be sufficient for our purpose. The most modern form of this instrument by Elliott Brothers is represented in Fig. 7156. The diaphragm is carried by an internal tube, which is nearly equal in length to the external tube A. The external tube is sprung at its aperture, and gives a steady and even motion to the internal tube, which is thrust out, and drawn in, to adjust the focus for objects at different distances by means of the milled-headed screw B. The spirit level is placed above the telescope, and attached to it by a hinge C at one end, and a capstan-headed screw D at the other, by means of which the bubble can be brought to the centre of its run, when the line of collimation is adjusted.

7156.



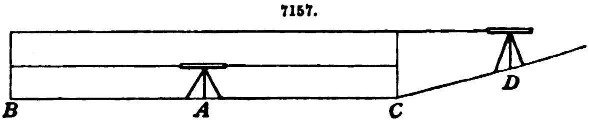
The telescope is attached to a horizontal bar E E, but room is just left between the telescope and the bar for a compass-box if required. A circular level F is placed upon the horizontal bar E E, parallel to the principal level G, by which the instrument can be set up at once with the axis nearly vertical.

The telescope is attached to the horizontal bar by countersunk screws at H H, by which the line of collimation is set perpendicular to the vertical axis, and the instrument is set up upon parallel plates, as in the case of the theodolite.

In setting up the instrument in the field, when it is in perfect adjustment, the telescope is placed over each pair of the parallel plate screws alternately, and they are moved till the bubble settles in the middle of the tube, and the operation is repeated till the telescope can be turned quite round upon the staff-head, without any change taking place in the position of the bubble.

Adjustments of the Level.—The adjustment for parallax is made in the same manner as for the theodolite. The collimating of a dumpy level is not so simple an operation as in the case of the Y level or the theodolite, since the telescope cannot be either rotated or reversed, that is, turned upside down in its collars or bearings. A simple method of placing the collimation in adjustment is as follows. In Fig. 7157 let the level be accurately set up at A, and readings taken at B and C two points equidistant from A. Let the level be shifted and set up at D, and readings again taken at B and C. Let these readings be respectively B^1, C^1, B_2, C_2. When the collimation is in adjustment we have $(B^1 - C^1) = B_2 - (C_2 + d)$, in which equation d is the difference of the curvature of the earth for the distances D B and D C. If $(B^1 - C^1) > B_2 - (C_2 + d)$, the line of collimation points downwards; but if $(B^1 - C^1) < B_2 - (C_2 + d)$, it points upwards. When $(B^1 - C^1) = (B_2 - C_2)$, the line of collimation will point downwards by an amount equal to the difference of the curvature of the earth for the distances D B and D C. Put $(B^1 - C^1) - (B_2 - C_2 - d) = \pm E$; then we have $BC : \pm E :: DB : \pm E^1$. The reading on the staff at B from station D should be equal to $B^1 \pm E^1$, and the horizontal wire can be adjusted to read this by means of the diaphragm screws K K in Fig. 7156. The following is Gravatt's method for collimating a dumpy. "On a tolerably level bit of ground drive three stakes at distances of about four or five chains apart. Call the first stake A, the second B, and the third C. Set up the level half-way between the stakes A and B, and take readings on the staff A′ and B′, then, although the instrument be out of adjustment, the two readings will be equidistant from the earth's centre.

7157.



"Now remove the instrument to a point half-way between B and C. Again read off the staff on B, and read also a staff placed on the stake, which call C. Now, by adding the difference of the readings on B, with its proper sign, to the reading on C, we get three points, say A′, B′, and C′, equidistant from the earth's centre, or in the same true level.

"Place the instrument at any short distance, say half a chain beyond it, and, using the bubble merely to see that you do not disturb the instrument, read all three staffs, or, to speak more correctly, get a reading from each of the stakes A, B, C; call these three readings A″, B″, C″. Now, if the stake B be half-way between A and C, then ought C″ − C′ − (A″ − A′) to be equal to 2 [B″ − B′ − (A″ − A′)]; but if not, alter the screws which adjust the diaphragm, and consequently the horizontal spider line, or wire, until such be the case, and then the instrument will be adjusted for collimation.

"To adjust the spirit bubble without removing the instrument, read the staff on A, say it reads A‴, then adding (A‴ − A′) with its proper sign to B′ we get a value, say B‴.

"Adjust the instrument by means of the parallel plate screws to read B‴ on the staff B.

"Now, by the screws attached to the bubble tube, bring the bubble into the centre of its run.

"The instrument will now be in complete practical adjustment for level, curvature, and horizontal refraction, for any distance not exceeding ten chains, the maximum error being only $\frac{1}{1000}$th of a foot."

Whatever be the distances between the stakes A, B, C, the following proportions ought to hold, namely;—

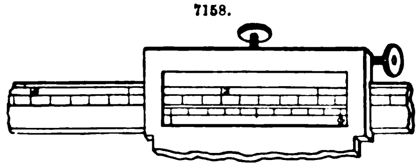
The distance from A : B : the distance A to C :: B″ − B′ − (A″ − A′) : C″ − C′ − (A″ − A′).

If this adjustment be made by one of the countersunk screws at H H, instead of the parallel plate screws, the line of collimation will be brought into its proper position with respect to the vertical axis.

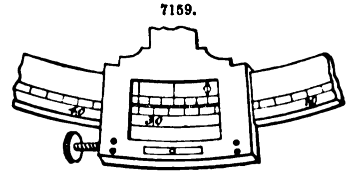
To set the Axis of the Telescope perpendicular to the Vertical Axis round which the Instrument turns, or, in other words, to make it traverse.—Place the telescope over two of the parallel plate screws, and move them, unscrewing one while screwing up the other, until the bubble of the level settles in the centre of its run. Then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and, if the bubble does not again settle at the same point as before, half the error must be corrected by turning one of the countersunk screws at H H, and the other half by turning the two parallel plate screws over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and repeat the operation again and again until the bubble remains in the centre of the tube during a complete revolution of the telescope. When the adjustments of a dumpy level are well and thoroughly made, the instrument will remain in excellent working order for many years. The remarks respecting the manner in which those adjustments should be made with regard to the theodolite are equally applicable to those of the level.

The Vernier, Fig. 7158, is so constructed as to slide evenly along the graduated limb of an instrument, and enables us to measure distances, or read off observations, with greater minuteness than we could without its aid. In another kind of vernier scale, the divisions on the lower or subsidiary scale are longer than those on the upper or primary scale; but in the vernier now to be described, the divisions are usually shorter than those upon the limb to which it is attached, the length of the graduated scale of the vernier being exactly equal to the length of a certain number (N − 1) of the divisions upon the limb, and the number (N) of divisions upon the vernier being one more than the number upon the same length of the limb.

7158.



7159.



Let, then, L represent the length of a division upon the limb, and L_1 the length of a division upon the vernier; so that $(N - 1)\ L = N\ L_1$; and therefore $L - L_1 = L - \frac{N-1}{N} L = \frac{1}{N} L$; or the defect of a division upon the vernier from a division upon the limb is equal to the Nth part of a division upon the limb, N being the number of divisions upon the vernier. If N divisions of the vernier were equal to (N + 1) divisions of the limb, or $(N + 1)\ L = N\ L_1$, then would

$$L_1 - L = \frac{N+1}{N} L - L = \frac{1}{N} L;$$

or the excess of a division upon the vernier above a division upon the limb would be equal to the Nth part of a division upon the limb. With this arrangement, however, we should have the inconvenience of reading the vernier backwards.

In Fig. 7159, six divisions of the vernier are equal to five divisions of the limb; and consequently the above defect, or L − V, is equal to a sixth part of a division upon the limb, or to 20′, since a division of the limb is equal to 2°.

In Fig. 7158, ten divisions of the vernier are equal to nine divisions of the limb; and consequently L − V is equal to a tenth part of a division upon the limb, or to the hundredth part of an inch, a division of the limb being equal to the tenth part of an inch.

We must, in reading, first look to the arrow, as pointing out the exact place upon the limb at which the required measurement is indicated. If, then, the stroke upon the vernier at the arrow exactly coincides with a stroke upon the limb, the reading at this stroke gives the measurement required; but, if the stroke at the arrow be a distance beyond a stroke upon the limb, then will this distance be equal to once, or twice, or thrice, the difference of a division upon the limb and upon the vernier, according as the stroke at the end of the first, or second, or third, division upon the vernier coincides with a stroke upon the limb.

The stroke upon the vernier, Fig. 7159, at the arrow falls beyond the stroke indicating 22° upon the limb, and the stroke at the end of the second division upon the vernier coincides with a stroke upon the limb; the reading therefore is 22° 40′.

The stroke upon the vernier, Fig. 7158, at the arrow falls beyond the stroke indicating one inch and three tenths upon the limb, and the stroke at the end of the sixth division upon the vernier

coincides with a stroke upon the limb; the reading therefore is 1·36 in., or one inch three tenths and six hundredths.

The limbs of the best sextants are now divided at every 10 minutes, and 59 of these parts are made equal to 60 divisions of their verniers. In this case $L - V = \frac{L}{60} = \frac{10'}{60'} = 10''$; so that these instruments can be read off by the aid of their verniers to an accuracy of 10 seconds. The verniers occupy on the limbs spaces equal to 9° 50′. That is, according to the graduation of the instrument; but as the angles observed by a sextant are double the angles moved over by the index, the limb of the instrument is graduated, as though it were double the size; so that the verniers really occupy an arc of 4° 55′ only.

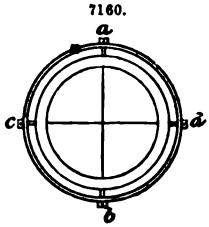
The limbs of small theodolites are generally divided at every 30 minutes, and 29 of these parts are made equal to 30 divisions of their verniers, which therefore enables us to read off to an accuracy of $\frac{30'}{30'}$, or 1′. In the mountain barometer, the scale being divided into $\frac{1}{100}$ths of an inch, 9 of these parts are made equal to 10 divisions of the vernier, which therefore enables us to read off to an accuracy of $\frac{1}{1000}$ths of an inch.

We have, in the above explanations, only considered the case of an exact coincidence between some one of the strokes upon the vernier and a stroke upon the limb. Suppose now that in Fig. 7159 the stroke at the end of the second division, instead of coinciding with a stroke upon the limb, fell a little beyond it, while the stroke at the end of the third division fell a little short of a stroke upon the limb; then the measurement indicated would be something between 22° 40′ and 23°, which the observer, should there be no other mechanism attached to the vernier, must estimate by guess, according to the best of his judgment.

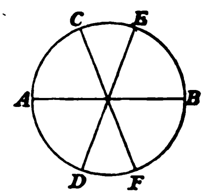
Diaphragms.—In looking through a telescope, a considerable field of view is embraced; but the measurements indicated by any instrument, of which the telescope may form a part, will only have reference to one particular point in this field of view, which particular point is considered as the centre of this field of view. We must therefore place some fixed point in the field of view, and in the focus of the eye-piece, and the point to which the measurement will have reference will be that point of the object viewed, which appears to be coincident with this fixed point, or which, according to the technical phrase, is bisected by the fixed point.

The intersection of two fixed lines will furnish us with such a fixed point, and consequently two lines of spider's thread, Fig. 7160, are fixed at right angles to each other in the focus of the eye-piece. They are attached by a little gum to a brass ring of smaller dimensions than the tube of the telescope, and which is fixed to the tube by four small screws, *a*, *b*, *c*, *d*, and constitutes the diaphragm in its simplest form. If the screw *d* be eased, while at the same time *c* is tightened, the ring will be moved to the left; but if *c* be eased and *d* tightened, the ring will be moved to the right; and in a like manner it may be moved up or down by means of the screws *a* and *b*.

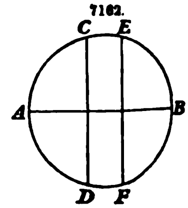
7160.



7161.



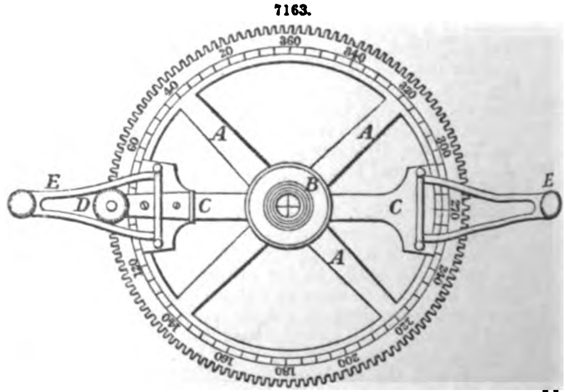
7162.



The diaphragm mostly placed in these telescopes of theodolites is shown in Fig. 7161, and that in those of levels in Fig. 7162. The two vertical lines in the latter, C D and E F, serve to show at a glance when the staff is held vertical in one plane.

Plotting Surveys.—The principal instrument used in laying down the points of a large survey, is the protractor. When considerable accuracy is required, a semicircular, or, better still, a circular protractor should be used, similar to that represented in Fig. 7163. The circumference is a complete circle, and attached to the centre by four arms, or radii, A, A, A, A. At the centre there is an open space, which is surrounded by a ring or collar B, which carries two radial bars C, C. To the extremity of one bar is a pinion D, working in a toothed rack quite round the outer circumference of the protractor. To the opposite extremity of the other bar C, is fixed a vernier, which subdivides the primary divisions on the protractor to single minutes, and by estimation to thirty seconds. This vernier, as may readily be understood from the engraving, is

7163.



carried round the protractor by turning the pinion D. Upon each radial bar C, is placed a branch E, carrying at its extremity a fine steel pricker, whose point is kept above the surface of the paper by a spring placed under its support, which gives way when the branch is pressed downwards, and allows the point to make the necessary puncture in the paper. The branches E, E, are attached to the bars C, C, with a joint which admits of their being folded backwards over the instrument when not in use, and for packing in its case. The centre of the instrument is represented by the intersection of two lines drawn at right angles to each other on a piece of plate glass, which enables the person using it to place it so that the centre, or intersection of the cross lines, may coincide with any given point on the plan. If the instrument is in correct order, a line connecting the fine pricking points with each other would pass through the centre of the instrument, as denoted by the before-mentioned intersection of the cross lines upon the glass, which, it may be observed, are drawn so nearly level with the under surface of the instrument as to do away with any serious amount of parallax, when setting the instrument over a point from which any angular lines are intended to be drawn. In using this instrument, the vernier should first be set to zero, which is at the division marked 360, on the divided limb, and then placed on the paper, so that the two fine steel points may be on the given line, from whence other and angular lines are to be drawn, and the centre of the instrument coincide with the given angular point on such line. This done, press the protractor gently down, which will fix it in position by means of very fine points on the under side. It is now ready to lay off the given angle, or any number of angles that may be required, which is done by turning the pinion D till the opposite vernier reads the required angle. Then press downwards the branches E, E, which will cause the points to make punctures in the paper at opposite sides of the circle; which being afterwards connected, the line will pass through the given angular point, if the instrument was first correctly set. In this manner, at one setting of the instrument, a great number of angles, or a complete circular protractor, may be laid off from the same point.

The most accurate method of laying down on paper any triangle, is to calculate the length of the sides, and lay them down by beam compasses, if they are too long for ordinary compasses. With respect to the use of the minor instruments employed in plotting and office drawing generally, the best course for the beginner to adopt is to purchase a good case, and with a little practice he will soon begin to find out their value and several uses.

See DISTANCES.

SWITCH. FR., *Aiguille, switch*; GER., *Weichschiene*; ITAL., *Sviatoio*; SPAN., *Cambio de via.*

See PERMANENT WAY.

TAP. FR., *Taraud*; GER., *Schraubenbohrer*; ITAL., *Maschio*; SPAN., *Macho de tarraja.*

In an engineering sense, a tap is a conical screw made of hardened steel, and grooved longitudinally, for cutting threads in nuts, and the like. A *tap-bolt* is a bolt with a thread on one end and a head on the other end, to be screwed into some fixed part, instead of passing through the part and receiving a nut. See HAND-TOOLS.

TAPPET. FR., *Toc*; GER., *Mitnehmer*; ITAL., *Arresto*; SPAN., *Palanca de escape.*

A *tappet* is a small lever or projection intended to tap or touch lightly something else with a view to change or regulate motion. For instance, a *tappet-motion* is a valve-motion worked by tappets, from a reciprocating part of a steam-engine, without either eccentric or cam.

TELEGRAPHY. FR., *Télégraphie*; GER., *Telegraphie*; ITAL., *Telegrafia*; SPAN., *Telegrafia.*

In the present article we purpose to treat the subject of telegraphy solely from an engineering point of view. The rapid and extraordinary development of the telegraphic system has rendered this part of the subject, namely, the construction and maintenance of the vast network of lines of communication, one of the highest importance, and the wide and varied experience which has been gained in all parts of the known world has furnished results from which reliable and definite information may be obtained for future guidance. To bring together these results and to impart this practical information is our present object. We shall therefore introduce only so much of the science of electricity as is necessary to the proper execution of the above-mentioned work. A minute scientific investigation of the numerous interesting facts relating to electric currents would be out of place here, and must consequently be left to the more appropriate pages of special treatises.

Batteries.—The nature, construction, and relative efficiency of the several batteries now in use having been fully described in former articles, see Battery, Boring and Blasting, and Electro-metallurgy, there remains but little to be said on this subject. The most constant and economical battery is that modification of Daniell's in which sulphate of zinc is used in the zinc cell instead of sulphuric acid. The greatest effect will, doubtless, be obtained when the porous cell is very thin; but it is desirable, in order to prevent the mixing of the two fluids as much as possible, to increase its thickness, and even to grease its back and sides; for when the cell is thin, the waste of sulphate of copper is as great when the battery is idle as when it is in use. This sulphate of copper should not be crushed, for when such is the case, the powder of the crushed crystals is apt to cement the whole into an almost insoluble mass at the bottom of the cell. When specially ordered, it may be obtained in crystals about the size of a hazel-nut.

The zinc, which is cast, should not contain more than 2 or 3 per cent. of impurities. When the zinc solution becomes strong, it crystallizes on the sides of the cell; the liquid then rises by capillary attraction between the crystals and the cell, and is apt to creep over the top and down the outer side of the cell, thus forming in time a kind of siphon which will often half empty the cell. The readiness with which gutta-percha is affected in this way has led to its almost complete abandonment. The evil may be lessened by dipping the cell, after having thoroughly dried and warmed it, about half an inch in a warm mixture of paraffin and paraffin oil. In some instances the copper plate has been placed at the bottom and the zinc at the top of the cell, the solutions being separated only by their difference in specific gravity. This arrangement, though energetic for a time, and having very little resistance, is inconstant and wasteful, as the copper solution rises rapidly to the zinc and is thrown down by it. In all cases the zinc should hang vertically, and should not

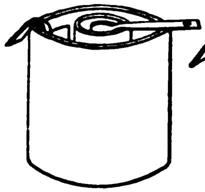
cross or face the copper, for when placed horizontally hydrogen accumulates under it and isolates it from the liquid.

Thirty cells of a battery of this kind are sufficient for a line of 200 miles if the insulation is good. On long lines subject to loss in wet weather, or when the insulation is bad, it is necessary to use larger cells. A better effect will be obtained by increasing the size of the cells than by adding extra cells in series.

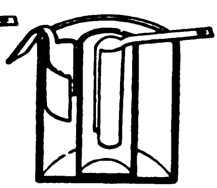
As supplementary to the description previously given of the several kinds of battery, we add the following, to illustrate those varieties which are employed for telegraphic purposes.

Daniell's element consists of a pole of sheet copper in a saturated solution of sulphate of copper, and a pole of amalgamated zinc in dilute sulphuric acid. These two solutions are separated by a porous diaphragm. The outer casing of this element is usually of stoneware, and is of the form shown in Figs. 7164, 7165. Glass is sometimes employed instead of stoneware, but is not generally so suitable.

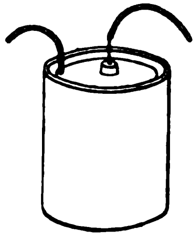
7164.



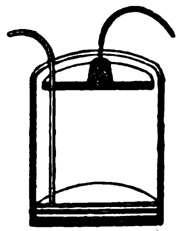
7165.



7165A.



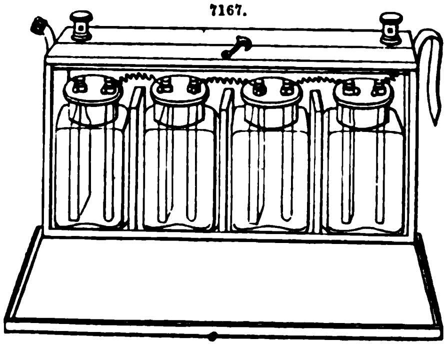
7166.



Minotti's, Figs. 7165A, 7166, element is a simple and inexpensive form of Daniell's element. It consists of a brown earthenware jar, at the bottom of which is placed a disc of sheet copper connected to an insulated wire. The jar is half filled with sulphate of copper crystals, over which a disc of felt is placed, and above this a thick layer of saw-dust to act as a diaphragm. The zinc plate is circular and lies upon the saw-dust. When in use, the cell is filled up with acidulated water. Sometimes a thin layer of oil is placed above this to prevent evaporation.

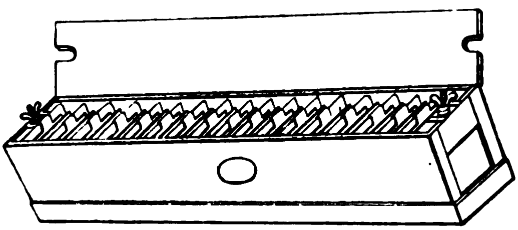
Marié-Davy's element consists of a carbon pole in a paste of protosulphate of mercury and water contained in a porous pot, and a zinc pole in dilute sulphuric acid. Fig. 7167 represents a portable form of this battery, well adapted for travelling and testing purposes. The poles are suspended in a glass jar sealed at the top. This is a powerful and constant battery.

7167.

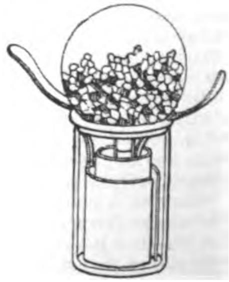


7168.

7169.



7170



Leclanché's element has a cylinder of amalgamated zinc suspended in a solution of ordinary salammoniac, the negative pole being a prism of carbon surrounded in a porous cell by a pulverized mixture, tightly packed, of peroxide of manganese and carbon. The whole is contained in a glass jar, as in Fig. 7168. This element is powerful, clean in its action, and does not deteriorate when not in use. It is much employed on the French railways, but it has not met with much favour in England.

Fig. 7169 is a common modification of Daniell's battery. It consists of a teak trough divided into cells by plates of slate, the whole being covered with marine glue. The cells are subdivided by porous divisions, and the zinc and copper plates are suspended alternately in the divisions thus formed. Usually this form of battery consists of twelve cells.

Another modification of Daniell's, and known as the Globe Reservoir Battery, is represented by Fig. 7170. This form is more constant and regular in its action than the preceding; it will last for a period of from twelve to fifteen months without attention.

Wire.—The most durable portion of a line of telegraph is the wire. In no instance has it been necessary to re-wire even the oldest line when not exposed to any specially destructive agency. The kind universally adopted for land lines is galvanized iron wire, and experience has shown that it is admirably suited to the purpose. But durable as this wire is when erected in the open country, in towns, and especially manufacturing towns, it is quickly destroyed. The same destruction also takes place in tunnels and in the neighbourhood of chemical works. Attempts have been more or less successfully made to protect the wire from these influences by means of paint, and, in some instances, gas-tar. If the operation is performed at the manufactory, the paint, or other coating, will be rubbed off in transit from place to place and in course of erection, and as corrosion will immediately be set up at such spots, the benefit of the coating in other parts is nullified. On the other hand, the difficulty and expense of painting after the wires are fixed to the poles are great. The process can, however, be easily performed on the ground before raising them to their positions on the poles. But in this case, unless great care be exercised to prevent the removal of the paint from the points of support, as well as to ensure the wires being perfectly dry, the results will not be satisfactory. The only plan that may be regarded as really successful, is to run the wire through paint or some bituminous preparation, and to immediately spin round it hemp or cotton well saturated with the same compound. This protects the coating from abrasion, and also forms of itself an efficient protective covering.

On the continent of Europe it was a common practice to use ungalvanized wire of a larger gauge, the extra quantity of metal being supposed capable of giving the wire as long a life as the smaller galvanized wire. This practice has never been adopted in England, and it is being discontinued elsewhere. The process of galvanizing slightly hardens the metal, and considerably lessens its capability of stretching; but its ultimate tensile strength does not seem to be affected by the operation. To test the thickness of the zinc coating, dissolve 1 lb. of sulphate of copper in 5 lbs. of water, and, plunging the wire into the solution, let it remain immersed one minute; then wipe it clean, and repeat the process four times. If, after the fourth immersion, the wire still appears black, the zinc has not been all removed, and it may be thence inferred that the galvanizing was well performed. But if the wire has a copper hue, the iron has been exposed, thus showing that the coating was too thin.

The quality of the wire used for telegraphic purposes is a matter of the highest importance, and one that usually receives very careful attention. For it must be borne in mind when specifying wire, that frequent derangement of the line in consequence of breakages will speedily absorb a small saving effected in the first cost, besides which, the annoyance caused by such derangements is very great. It may be observed, however, that great tensile strength is not of primary importance for ordinary work. What is required is rather a wire that will bear the bending necessary to make joints, and to fix it to the insulators, than one that will bear a great tensile strain. Telegraph wire may be tested for this quality by placing it in a vice and ascertaining the number of times it may be bent to a right angle without breaking. Care must be taken that the edges of the vice do not cut the wire, or the results of the experiment will be vitiated. Soft wire, though of inferior tensile strength, will bear this test better than hard wire.

Wire is prepared by being drawn down to the required size from rods of rolled iron. These rods should be perfectly free from cinders or dirt, as the presence of such impurities would occasion imperfections in the wire. All imperfections of this nature, as well as splits in drawing and imperfect welds, should be carefully sought for and broken out before the wire is erected. For this purpose, it was usual formerly to lay the wire out in the line and to stretch it, and as this stretching removed all tendency to spring and curl from being coiled in bundles, the process was termed killing. Wire when killed is very easy to handle. This killing is now done at the manufactory by stretching it over a drum after it has been passed between rollers to break out the splits. The expense of these operations will be amply repaid by a decrease of labour in erection and fewer interruptions of communication occasioned by breakage. It should also be observed that killed wire is scarcely acted upon by the wind at all, for it may be seen hanging comparatively still on the poles, while others which still retain their irregularities are swinging violently to and fro. These irregularities are also liable to occasion permanent contact, should the wires be blown together. Such an accident cannot occur with killed wire.

The operation of jointing telegraph wire is an important one, and demands great care. The most approved form of joint is that known as the Britannia, Fig. 7171. This joint is made by bending up the ends of the wires to be joined, binding them firmly together with binding wire, and afterwards soldering the whole. The binding wire used for this purpose is, for No. 8 gauge, No. 16 B. W. G., and for larger sizes, No. 14 B. W. G., of the best charcoal iron galvanized. A twisted joint is not so strong as the Britannia, because the twisting renders the iron more liable to break. Another objection to the twisted joint is its size, which increases its tendency to cling when the wires are blown together. However strongly a joint may be made, it is not secure as regards conducting power unless it is soldered. Even the method which is sometimes adopted, of cleaning the ends and casting an ingot of metal over them, is not sufficient. Electrolysis, and consequently corrosion, invariably occurs in every connection if moisture is present. Chloride of zinc

7171.

is used for soldering; but when applied to any but perfectly clean and bright wire, it should contain a sufficient quantity of free acid to dissolve the oxide and remove the dirt. It is important that the operation of soldering should be performed quickly, and at as low a temperature as possible, especially with hard wire; because the heat softens the metal and diminishes its tensile strength. As regards strength, joints are greatly superior to welds, but a practical difficulty prevents their general adoption. When the wires are blown together, joints are very liable to catch and cause permanent contact, occasioning, of course, a stoppage of communication. For this reason, they should not be used at a greater distance than 10 ft. from the poles. To get rid, as far as possible, of both joints and welds, it is desirable to draw the wire in long lengths. As much as 80 lbs. of No. 8 wire, equal to one-fifth of a mile in length, may be drawn in one piece.

To test the tensile strength of telegraph wire, it is usual to place a length of 10 in. in a hydraulic machine; this length is chosen to render the calculation of the percentage of strain and elongation easy and convenient. Tested in this way, a good piece of No. 8 wire will break with a strain of about 1300 lbs. If tested with a scale and weights, and sufficient time is allowed for the wire to stretch after each addition of weight, it will break with a less strain, or about 1100 lbs. That such should be the case is self-evident when we consider that elongation diminishes the sectional area of the wire. The scale and weights afford the best test, since it approximates more nearly to the actual conditions that obtain in practice. Good wire begins to stretch with about half the breaking strain. It has been ascertained that when a sample will break in the testing machine with a strain of 1300 lbs., a length of 88 yds., which is the distance from pole to pole when there are 20 to the mile, will break in practice with a strain of about 1000 lbs. The following Tables of examples of stretching and breaking strains are given by Culley. The first Table shows the results of 27 different samples tested in 10-in. lengths by the hydraulic apparatus.

	Means.	Extremes.
No. 8 *Gauge.*		
Diameter before testing	0·151 in.	0·147 to 0·153 in.
„ after having been broken	0·140 „	0·136 „ 0·144 „
Percentage of stretch before breaking ..	20	19 „ 25
Strain required to stretch the wire	672 lbs.	600 „ 750 lbs.
Breaking strain	1318 „	1250 „ 1440 „
No. 11 *Gauge.*		
Diameter before testing	0·115 in.	0·112 „ 0·120 in.
„ after having been broken	0·106 „	0·100 „ 0·117 „
Percentage of stretch before breaking ..	20	19 „ 25
Strain required to stretch the wire	505 lbs.	400 „ 600 lbs.
Breaking strain	776 „	740 „ 850 „

The following are means of ten tests of wire of the same quality and from the same makers, tested in lengths of 33¼ in. by *scale and weight*, adding 56 lbs. at a time, gently and without jerk, and waiting until the wire had ceased to stretch before adding more weight;—

Percentage of stretch before breaking	11·2
Strain required to stretch the wire	904 lbs.
Breaking strain	1132 „

The following trials show the effects of annealing and of galvanizing;—

No. 8 Iron.	Mean Breaking Strain.	Mean Percentage of Stretch before breaking.
No. 1 *Sample.*	lbs.	
Before galvanizing	1138	18·75
After „	1169	12·88
No. 2 *Sample.*		
Before galvanizing	1090	19·39
After „	1194	13·09

Homogeneous Iron, Nos. 11 and 12.

	Breaking Strain.		Percentage of Stretch.	
	Mean.	Extremes.	Mean.	Extremes.
Before annealing	910 lbs.	830 to 1060 lbs.	·92	0·75 to 1·25
After „	612 „	560 „ 700 „	20·05	17·00 „ 21·50
Before galvanizing	612 „	560 „ 700 „	20·05	17·00 „ 21·50
After „	634 „	560 „ 700 „	11·64	9·00 „ 15·00

The process of galvanizing has been improved since these experiments were made, so that the elongation is not now so much affected.

The following Table, also due to Culley, shows some useful and important facts relating to iron telegraph wire.

B. W. Gauge.	Diameter.		Area of Section, square inches.	Weight of 100 Yards in lbs.	Weight of 1760 Yards in lbs.	Weight of 2029 Yards in lbs.	Length of 1 Cwt. in yards.	Breaking Strain in lbs.		B. W. Gauge.
	Inches.	Millimetres.						Soft Wire.	Hard Wire.	
00	0·363	9·21	0·103	102·00	1794	2068	110	8600	6000	00
0	0·331	8·40	0·086	84·72	1490	1718	132	7100	4750	0
1	0·300	7·61	0·071	68·75	1210	1395	162	6000	4000	1
2	0·280	7·11	0·062	59·90	1054	1215	187	4850	3400	2
3	0·260	6·60	0·053	51·65	909	1048	215	4000	2900	3
4	0·240	6·10	0·045	44·00	775	895	255	3400	2500	4
5	0·220	5·59	0·038	37·00	651	750	303	2950	2200	5
6	0·200	5·08	0·031	30·56	538	620	361	2500	1800	6
7	0·185	4·69	0·0265	26·15	461	531	428	2200	1520	7
8	0·170	4·31	0·023	22·10	389	448	509	1750	1200	8
9	0·155	3·93	0·0195	18·36	323	373	609	1500	950	9
10	0·140	3·55	0·016	14·97	264	305	747	1200	820	10
11	0·125	3·17	0·0125	11·95	211	244	939	820	650	11
12	0·110	2·79	0·010	9·24	163	188	1244	710	510	12
13	0·095	2·41	0·0071	7·05	124	143	1589	640	400	13
14	0·085	2·15	0·0057	5·51	97	112	2031	510	350	14
15	0·075	1·92	0·0044	4·29	76	87	2608	410	300	15
16	0·065	1·65	0·0033	3·22	57	66	3473	350	200	16
17	0·057	1·44	0·0026	2·48	44	50	4515	280	150	17
18	0·050	1·27	0·0020	1·91	34	39	5600	200	115	18
19	0·045	1·14	0·0016	1·55	27	31	7246	150	85	19
20	0·040	1·01	0·0013	1·22	21	24	9168	100	65	20
21	0·035	0·88	0·0010	0·94	17	20	11980	85	50	21
22	0·030	0·76	0·0007	0·69	12	14	16300	65	40	22

The Specification of the Electric Telegraph Company for iron wire was as follows;—

"The wire to be highly annealed, and very soft and pliable; it is not required to possess great tensile strength, but must be capable of elongating 18 per cent. without breaking after galvanizing.

"To be supplied in not less than 80-lb. pieces, and to be warranted not to contain any weld, join, or splice whatsoever, and to be free from all imperfections, flaws, sand splits, and other defects.

"The whole of the wire to be passed under and over three or more studs or pulleys placed in two lines, the wire passing over the pulleys in the upper line and under the others.

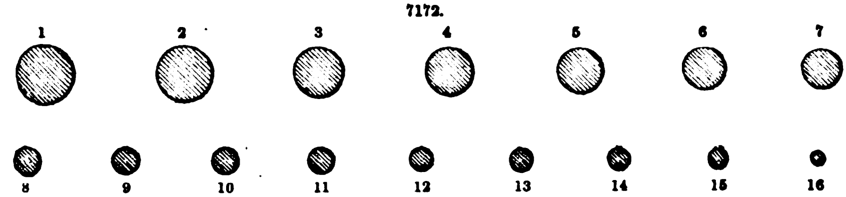
"The whole of the wire to be stretched 2 per cent. by machinery in the presence of the company's engineer or his representative, and to be tested, examined, and approved by him before leaving the works. The wire after being stretched to be coiled carefully, so as to contain no bends, but to resemble newly-drawn wire in its straightness.

"If during the process of testing the wire between the studs or pulleys, or during the process of stretching it, more than 5 per cent. of the bundles break, crack, or show any defect, the whole of the broken bundles to be rejected. If less than 5 per cent. prove defective, the wire will be accepted. The makers are not to attempt to weld, join, or otherwise splice any wire that may break or prove defective, but deliver it as it comes from the testing."

In ordering wire, a surplus of about 10 per cent. should be added as an allowance for slack and waste.

The size of the wire used for telegraph purposes is a matter of importance, and will to some extent be determined by the conditions under which the line is required to work. The accompanying diagram, Fig. 7172, shows the natural sizes of the wire used for telegraphic purposes. The larger the

7172.



wire the greater its conducting power, and the less its electrical resistance as compared with that of the insulators. In other words, the larger the wire, the greater the strength of the signal, which can be transmitted through it to any given distance. Thus the effects of bad insulation can be compensated, at least to a considerable degree, by increasing the size of the wire. The size usually adopted is that known as No. 8, Birmingham wire gauge, and it has been proved in practice to be

amply sufficient in conducting power, when insulation is good, for circuits not exceeding 400 miles. For railway purposes and short circuits generally, if economy in first cost is an object of importance, smaller sizes may be used. No. 10 will in most cases be sufficiently large, and for circuits of 100 miles No. 11 may be employed. If the circuit does not exceed 50 miles the latter size will be ample. For military telegraphs, where the circuits are short, and the wire has to be run up quickly, No. 12 is a suitable size.

But in order to carry out economy in this direction, insulation must be good; for it must be borne in mind that the conductibility of a wire is, other things being equal, in proportion to its size. Many instances might be cited in which, for moderate circuits, a No. 8 wire having worked badly in consequence of imperfect insulation, the difficulty has been removed by the substitution of a larger wire. Culley relates how the Admiralty circuit of No. 8 wire between London and Devonport worked badly some years since when insulation was comparatively imperfect. Complaints having become frequent, a No. 4 wire was substituted between Bristol and Plymouth. This wire was not better insulated than the smaller one, perhaps even not so well; but as soon as it was placed in circuits the complaints ceased, and have not since been renewed. Again, a fault occurred in the underground wire between Leith and Edinburgh, connected with the London and Leith circuit, which was of No. 8 wire. In this case, as in the former, the substitution of a No. 4 wire removed all difficulty in working, and the repair of the faulty portion could be proceeded with at leisure.

The length of span, or the distance from one support to the next, is determined by numerous conflicting conditions. Obviously the fewer the supports, the better will be the insulation, and as a reduction in the number of the supports diminishes at the same time the cost of construction, there are weighty reasons for making the span as long as possible. In the early days of telegraphy, the poles were set 30 to the mile; this number has been reduced to 24, 20, and, in a few instances, 17. An increase of span, however, introduces other conditions which speedily render further progress in that direction unprofitable. It does not appear that the wires have a greater tendency to blow into contact with each other in long than in short spans, provided they be all of the same gauge and are equal in tension, as under such conditions they keep time together in their oscillations. This objection therefore, though it has frequently been urged, is not a grave one. But a more important objection, and one that renders a less number than 20 poles to the mile in most cases a practical impossibility, is the risk of accident consequent on the additional height of the poles, rendered necessary by the greater dip, and the increased strain on the wires. The number usually adopted as best fulfilling the conditions imposed is 22, which gives a distance of 80 yds. from pole to pole, a convenient number for calculation. The ordinary dip on the wires in a span of this length is about 18 in. in mild weather; this gives with No. 8 wire a strain of about 420 lbs., its breaking weight being, as we have seen, 1100 lbs. The strain varies directly as the weight of the wire, and inversely as the dip or versine. When the latter is constant, it increases as the square of the span, and when the strain remains constant, the dip or versine increases in like manner; or, $L^2 : l^2 :: V : v$. Thus if the dip be 18 in. when there are 22 poles to the mile and the strain 420 lbs., with 11 poles to the mile we shall have a dip of 6 ft., or, if the dip remain at 18 in., a strain of 1680 lbs. From this it will be at once seen that a span of such a length is practically impossible. To find the strain in lbs. and the dip in inches approximately, the following formulæ are given by Latimer Clark; $s = \dfrac{l^2 \times w}{31 \cdot 43 \times v}$, and $v = \dfrac{l^2 \times w}{31 \cdot 43 \times s}$, in which s is the strain, v the dip, l the length of span in feet, and w the weight in cwts. of one statute mile.

Another objection to the adoption of long spans is the friction of the wire upon its supports occasioned by the action of the wind. In some instances where the wire has been supported upon very hard and smooth brown ware, and the spans have been short, no appreciable wear has been caused by this means in twenty-four years. But when the spans are long, and especially when the wires are supported upon soft porcelain, the wear is very rapid. And it must be borne in mind that as soon as the zinc is rubbed off, galvanic action may be set up so as to corrode the iron. No. 11 wire so frequently breaks from this cause on long spans that it has been found necessary to protect it at the supports by wrapping it with binding wire. Even No. 4 has been chafed on spans of over 100 yds.

In wiring a line, allowance must be made for variations in temperature. With 20 poles to the mile, a dip of 14 in. in a No. 8 wire is equivalent to a strain of 540 lbs., and the difference in dip between 54° and 25° Fahr. has been ascertained to be 3 in., so that if a wire be pulled up to 14 in. in mild weather, it will assume at 25° a dip of 11 in. only, which is equivalent to a strain of 700 lbs., more than half its breaking strain. Culley mentions an experiment in which a 200-ft. length of No. 8 wire was suspended between two rigid supports so that the dip could be read off upon a scale. The results were a dip of 17 in. at 33°, 18·5 in. at 43°, 19·5 in. at 53°, and 20·25 in. at 63°.

The wire should be always tightly bound to the insulator, so as to reduce the friction to a minimum. Formerly it was usual to allow the wires to pass freely through the insulators, and to strain them by a drum or ratchet at every half mile. This method allowed a broken wire to run down half a mile in every case. The present practice is to bind the wire to every pole, so that it can never, if properly bound, run down more than 100 or 200 yds. The wire used for binding is No. 16, and care should be taken in applying it to make all the turns in the same direction, as otherwise it will not be firm; for the main wire is twisted somewhat in the process, and when it resumes its normal position, one side of the binding will be slackened, if the turns are made in opposite directions. When the position of the poles is changed, or when a line is reset, the wire should be carefully examined, and worn places either cut out, or, if the wear be slight, bound over with binding wire.

The distance through which a broken wire will run down is shown by the following experiments, related by Culley, to depend very much on the way in which it is bound;—

1. "On a line of 24 poles to the mile a No. 4 wire was bound with a single No. 16 wire at each insulator, and securely soldered so that it could not slip. When filed through in the middle of its length, it tore itself from the fastenings throughout the whole distance.

2. "Next it was bound as before, but soldered at every fourth pole. It then broke away from 20 poles only. Here the unsoldered bindings allowed it to slip a little, and so eased the strain.

3. "Thirdly, it was bound doubly strong, but not soldered. The first binding stretched a little, and all the arms were strained, but it did not tear itself away from a single pole. The wire, therefore, should be so bound as to slip a very little at each support, and so prevent a sudden jerk."

The wires should be placed as far apart as possible upon the poles, to prevent their being blown into contact with each other. As they are still more liable to contact in the vertical plane, arms of different lengths should be used so that the wires may not hang vertically one over the other, or when space is limited, the insulators may be alternate instead of opposite. By these means, the danger of a broken wire falling across the others is obviated.

Poles.—The material employed for telegraph poles is generally wood. Iron is, in many respects, a more suitable material, it is stronger for a given size, lighter in appearance, and far more durable; but the difference of cost is at present too great to allow it to compete successfully with wood. Except in certain cases, therefore, which we shall describe later, the latter material continues to be employed.

The dimensions of a wooden telegraph-pole are usually 18 ft. in length by a diameter of 5 in. at the upper end. For level crossings, bridges and terminal poles, greater lengths up to 25 ft. are required. In all cases they should contain the natural butt of the tree, the tops of trees being quite unsuitable for this purpose. The latter are sometimes employed where economy in first cost is considered to be of primary importance; but their rapid decay renders the subsequent cost of maintenance proportionately great, and when the difficulties attending a frequent resetting are taken into account, they must be considered as leading to a false economy. The kind of wood employed is generally larch; other kinds are, however, suitable. Memel pine is very durable, but is too expensive for common use. Pitch pine is still more lasting; the original poles on the London and South-Western Railway were of this pine, and many of them are still sound, 1874, though they were erected nearly thirty years ago. Spruce and Scotch fir decay very quickly, being scarcely equal in durability to the tops of larch trees.

Larch should be cut in the winter when the sap is down and seasoned with the bark on. The bark must, however, be removed as soon as the seasoning is complete, or the wood will be attacked by insects. During the process of seasoning, the poles should be so stacked that they may be exposed to the wind on all sides. Larch grown upon hilly ground is more durable than that raised in other situations, by reason of its containing more heartwood. But such poles are seldom straight. Unseasoned larch lasts, on an average, about seven years; when properly prepared and seasoned, it will last twice as long. If grown upon hilly ground, and having consequently the heartwood well developed, unseasoned larch will last from twelve to fifteen years. The durability of unseasoned poles may be considerably increased by charring them over a slow fire. But in such a case they should not be tarred or painted until they have stood long enough to become seasoned, or the wood will decay under the tar while remaining sound above. When the seasoning has advanced sufficiently, the ground around the pole should be opened for a depth of about a foot, and after the pole has become quite dry, the tar applied. The results will be more satisfactory if the tar be applied hot. With seasoned poles, the application of the tar should follow immediately the process of charring, before the wood has had time to cool.

Chemical means of preserving wood have been successfully applied to telegraph poles, and the constantly increasing cost of timber will probably lead to their general adoption. Only two processes have hitherto been found to give satisfactory results, namely, creosoting and boucherizing. The former does not fail in any soil, and it possesses the advantage of not corroding iron. The injection, however, can only be carried on at a large depôt, by reason of the appliances requisite. Boucherizing is free from this objection, as the necessary apparatus is both inexpensive and portable; and as the process may be readily overlooked and performed, it may be carried out in the forest. The method of creosoting is so well known that we need not describe it here; a few remarks on it will be found under Kyanizing.

Wooden poles should be set from one-fourth to one-fifth of their length in the ground, according to the nature of the soil and the strain they will have to bear. With a less depth of setting, they will not have a sufficient hold on the ground in wet weather. Even with a depth of one-fourth, poles are frequently blown out after a long rainy season, if the soil be weak. The severest strain is thrown upon the poles when a snow storm, in which the snow freezes upon the wires, is sueceeded by a high wind. Against such a case no practical strength of construction seems secure.

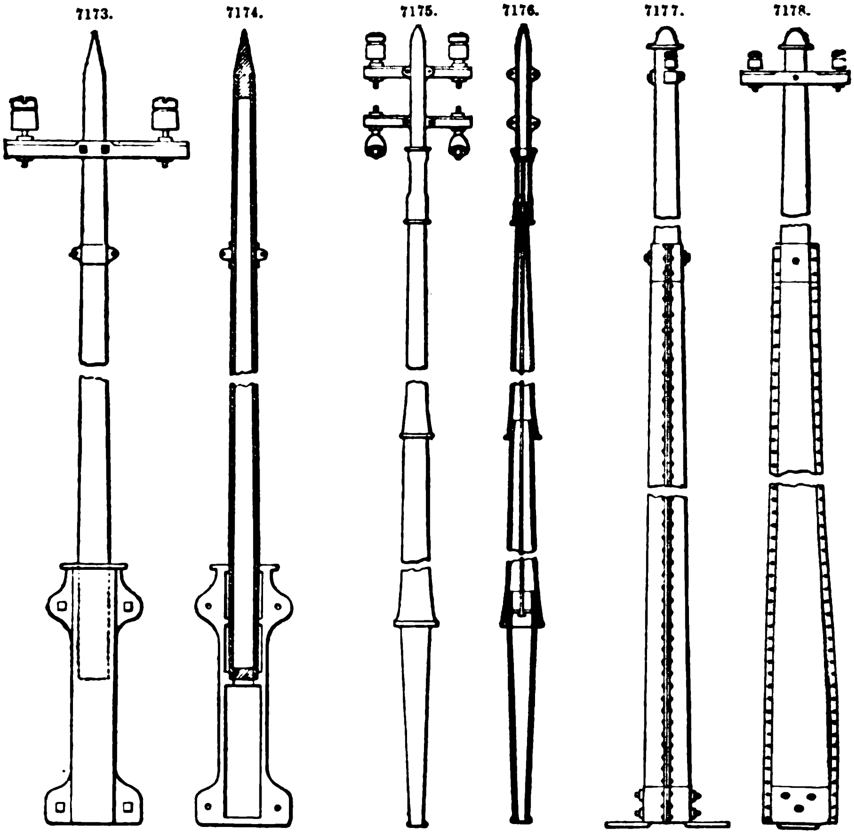
On curves, and especially where the direction of the line is changed at an angle, stay-wires are required. These generally consist of two or three lengths of the line wire twisted together and fixed to a plate buried from 18 in. to 30 in. beneath the surface of the ground, or to some other more convenient object. About 5 per cent. of the wire used is required for stays.

Wooden poles decay most rapidly at the ground line, and they are frequently repaired by scarfing at their point. But to ensure satisfactory results, the repair must be effected before the decay has progressed far, and well seasoned or creosoted wood should be used for the scarfs. The experience of many telegraph engineers, however, seems to show that repairing poles does not pay.

Iron poles, on account of their more elegant appearance, are being substituted for wooden ones in towns. They are also very suitable for use in foreign and especially mountainous countries, because, being capable of separation into parts, their transport is more easily and cheaply effected. Another, and frequently a great advantage, is that they are proof against the ravages of the white ant. Figs. 7173, 7174, represent a wrought-iron tubular pole as manufactured by Warden and Co. It consists of two parts, a cast-iron base and a wrought-iron stem. The base is made in two halves,

and is 4 ft. in length, 3 ft. of this length being fixed below ground; the two halves embrace the stem, and are secured by bolts. The stem is a taper wrought-iron tube, from 15 to 22 ft. in length, making the length of the complete pole from 18 to 25 ft. The weight of the cast-iron base 110 lbs., and that of the 15-ft. stem 70 lbs., making the total weight of the 18-ft. pole 180 lbs. These poles are also manufactured in a form suitable for use on rock, where it is not possible to sink a pole of sufficient size to receive the ordinary base. The cast-iron base is, in this case, dispensed with, and the base of the tube is secured to the rock by means of a jagged bolt leaded into the rock. Iron stays of strong gas-pipe are used to support the pole. The stays have screwed ends attached to collars surrounding the pole at about 4 ft. from the ground, the lower ends being provided with jagged bolts also leaded into the rock. These poles are extensively used on the Delhi, Mauritius, and some other railways, where they are said to have been found very efficient.

7173. 7174. 7175. 7176. 7177. 7178.



Figs. 7175, 7176, a cast-iron telescopic pole by the same makers. This pole is made in three pieces wholly of cast iron. The base is conical, the smaller end being fixed downwards, and the stem consists of two tubes tapering in the contrary direction to the base. The upper length sockets over the lower section, which in its turn sockets over the base; an iron rod or wire secured at both ends is passed through the interior of the pole to keep the parts firmly together when in use. A cast-iron socket-piece is fixed to the top of the pole, into which socket-piece a suitable support for the cross-arms and insulators is fitted.

These poles pack very conveniently for transit, the parts being so arranged that they slide one into the other for this purpose. The weight of an 18-ft. pole complete is about 2 cwt.

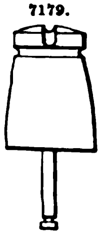
Figs. 7177, 7178, are of Morton's oval telegraph pole, consisting of a galvanized wrought-iron tapered tube, in two pieces, riveted together. The lower end of the tube is fitted with a cast-iron foot or base, and a wooden top, finished by a small galvanized cast-iron cap, which may or may not support an insulator, is socketed into the upper end of the tube. The section of the tube is oval, and the rib or flange containing the rivets, on each side of the pole, is further stiffened by a plate of iron inserted between the flanges; this adds greatly to the strength of the pole in the direction in which strength is chiefly required.

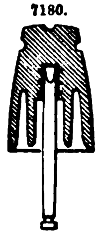
The galvanized-iron tube is 12 ft. in length. The wooden top varies according to the desired length of the pole; for an 18-ft. pole its length is 6 ft., and its diameter at top 3½ in. The weight of the tube and cast-iron foot is 98 lbs., and that of the wooden top, 20 lbs., making the total weight of an 18-ft. pole complete, 118 lbs.

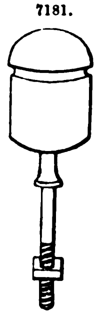
Insulators.—There are many substances which insulate well, but which, from their not possessing certain other qualities, are quite unsuitable for purposes of insulation. In choosing a material

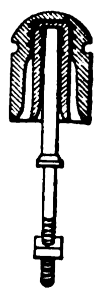
a primary point is to ascertain whether it will insulate perfectly independently of the nature of its surface, for it must be borne in mind that the process of glazing an insulator is not to improve the insulating qualities of the material, but to give it a hard smooth surface that shall be an advantage in other respects, the object of glazing being chiefly to prevent the wearing of the wire by friction, and the adhesion of dust and dirt. Another condition is that the material shall resist the deposition and the retention of moisture. Thus a porous substance is quite unsuitable. The only material that insulates perfectly and possesses naturally a hard smooth surface is glass; but experience has shown it to possess also certain defects which have rendered its abandonment necessary. Moisture is very rapidly deposited on it, and in such a way as to form a continuous film, and its fragility is such that it cannot be relied upon. It is, however, still extensively used in Switzerland, and a novel form of insulator of blown-glass has been introduced in America. The form is that of a narrow-necked bottle, and several trials made to test its efficiency are said to have given satisfactory results. Ebonite is for a time the best available material for insulators; it insulates well, it very effectively resists the deposition of moisture, and it is very strong; but a few months' exposure to atmospheric influences makes its surface rough and spongy, and consequently favourable to the retention of moisture and dust. When in this state, it is inferior to earthenware; but we have only to re-polish it to render its behaviour as good as when first erected. Such a defect, however, renders it unsuitable for general adoption. Next to glass, porcelain possesses the best surface for resisting accumulations of dust and dirt, and for this reason it is selected wherever the line is exposed to smoke, dust, or salt spray. It does not appear to insulate better than good stoneware, whilst its cost is much greater. Brown stoneware is the cheapest, and for ordinary use the best, material for insulators. It is usually made from clay dug on the spot, and as it does not require an admixture of other materials, it is likely to be uniformly good.

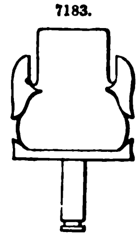
The forms of insulators are very various. The most approved, and those which are now most commonly used, are known as Clark's and Varley's. Figs. 7179, 7180, represent Clark's insulators in elevation and section. It consists of a double bell in white porcelain, and is provided with a taper galvanized wrought-iron stem. This form of insulator is extensively used, and when of brown stoneware is found to be both efficient and economical. Figs. 7181, 7182, are of Varley's double insulator. It is of brown stoneware, and is fitted with galvanized wrought-iron shoulder-bolt and nut. These insulators consist of an outer and an inner bell, manufactured and tested separately before union. They are made in three sizes to suit No. 4, No. 8, and No. 11 wire. For efficiency and economy of maintenance this form of insulator is probably unequalled. Figs. 7183, 7184, an iron-protected insulator, consisting of a double bell of either white porcelain or stoneware, protected by

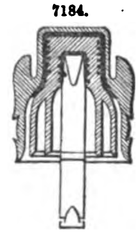
7179.


7180.


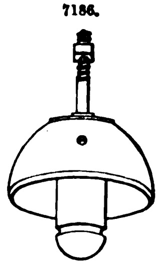
7181.


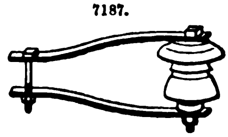
7182.


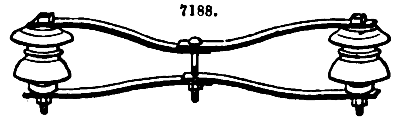
7183.


7184.


7185.


7186.


7187.


7188.


a galvanized cast-iron cap, and provided with a galvanized steel, or wrought-iron stem. Fig. 7185 is another iron-protected insulator also consisting of a double bell of either porcelain or stoneware, and protected by a galvanized cast-iron cap perforated to admit of the lower portion of the insulator being washed by the rain. Fig. 7186 is a common form of terminal insulator, known as the umbrella form. It usually consists of a stout insulator of either porcelain or stoneware, and is provided with a strong galvanized bolt, with nut and washers, so as to be suitable for both wooden and iron arms. Bright's double-bell shackle insulator for terminating wires is represented in Fig. 7187. These are of porcelain, and the straps and bolts are either painted or galvanized. This form of insulator may be fitted in pairs, as shown in Fig. 7188, for terminating and leading in wires to stations, or for use on sharp curves and at angles.

The advantages of iron caps have been greatly overrated. Indeed, it seems probable that, except in certain exposed situations, their use is attended with positive disadvantage; for, though they

keep the outer surface dry, they do not prevent the accumulation of dust, and they afford a harbour for insects, especially spiders, whose webs conduct when damp. Moreover, they do not altogether prevent the deposition of moisture, so that this advantage which is claimed for them is not wholly real, while, by protecting the surface from the washing action of the rain, they tend to aggravate the evil caused by dust. The only means of protecting insulators against the latter is to make their surfaces hard and smooth, and then to leave them completely exposed to the weather. This is especially the case with coast lines, where the deposition of salt is more troublesome than dust. For this reason an insulator should not be placed under an arm, but above it, as in the former case the surface of the insulator is partially protected, and is consequently always dirty. In some parts insects are very troublesome, and when the line passes near or under trees, it is well to make the openings of the insulators wide so as to be less attractive to insects and more easily cleaned. Paraffin oil is perfectly effectual in repelling insects for a time, and it possesses the additional advantage of improving the insulation; the latter effect will last six months. Creosote in the poles will also repel insects so long as its smell remains.

To test insulators in the trough, place the insulating cup in a vessel of water made slightly acid; some acidulated water being poured into the cup, smear a little turps on the rim, and let it remain twenty-four hours. At the expiration of this time immerse the poles of a battery in the water, one inside and the other outside the cup, a very sensible galvanometer having been included in the circuit. If the needle exhibits any deflection, the circuit is complete, and consequently the insulator is imperfect. The imperfection usually arises from porosity and cracks in the material.

Culley gives the following method of ascertaining approximately the comparative value of different shapes;—

"The best method of testing is to fix as large a number as convenient, certainly not less than ten of each kind, upon a pole, connecting them by a wire to the present line wire, and fixing a second independent wire to their bolts, to represent the earth, and to determine the leakage from one wire to the other.

"To obtain good results, the following precautions are necessary:—Fix a pole not less than 20 ft. high in an open place not sheltered in any way on any side, place the arms on which the insulators are to be fixed at least 2 ft. apart, the insulators themselves a foot apart. Do not place all of the same kind together, but rather alternate or mix them as much as possible so as to obtain an average of exposure for all.

"Take special care that the wire representing the line touches each one closely all round and uniformly as to the number of turns; let it be all the same gauge. The object is to ensure equal surfaces of metal in contact with the porcelain, because the leakage takes place from each point of the wire over the surface of the insulator, and consequently if the wire does not touch uniformly, the leakage will vary with the variation of the surfaces in contact. If possible, divide each set of ten in half, making duplicate sets of five each. If these do not test alike, there is probably a defective insulator among them, which will vitiate the test, and which must be removed. Never use separate gutta-percha or other insulated leads from each set to the testing room, for these will become more or less damp on their surface, and will vary in insulation, one from the other, more perhaps than the insulators themselves. Use only one wire, employing a man to shift it from one set to the other.

"It is seldom that rain falls steadily and uniformly, so that if the testing lasts even five minutes there will often be a considerable difference in the amount of moisture during the interval. After testing all the sets, commence again in the reverse order; if the two series agree, the observation is a good one. As the object of such tests is not so much to find the *absolute* resistance of the several specimens as to ascertain their *relative* value, it is better not to occupy time in testing units, but rather to read a simple deflection so that the tests may be made as rapidly as possible, ensuring the greatest possible uniformity of circumstance; but, with the greatest precaution, the tests will frequently be extremely anomalous.

"Speaking generally, the best insulator is not that which tests best when quite new, but that which bears exposure the best; and therefore no tests are of any value which have not extended over several months. However carefully this experimental testing may be conducted, it is not altogether satisfactory; the only true method is to insulate two wires on the same poles for a distance of ten miles or more, and to test them every damp day for six months. It is useless in any case to test in dry weather.

"I will give the result of tests made in a situation quite free from insects, but somewhat smoky —Gloucester Road, Regent's Park, during twelve months, 1868–69;—

Mean Comparative Loss.

Brooks' double cup (*American glass*)	5	parts leakage.
Varley's ordinary size	20	" "
Porcelain	26	" "
Double cones, porcelain	51	" "
Shackles "	82	" "

"The porcelain insulators were very much wider than the Varley's to render them less liable to be blocked up by insects. The test, therefore, does not show the difference between stoneware and porcelain so much as that between a wide and a narrow opening.

"The effect of iron caps may be judged from the following;—

Porcelain, without caps	38	parts leakage.
" with open caps (or cages)	44	" "
" with closed caps	55	" "
Small earthenware insulator, without caps ..	40	" "
" " " with open caps	50	" "

"The tests also show that with a wide cup a bracket gives a better result than an arm, probably because splashing is avoided; the leakage being 26 and 38 respectively.

"New insulators may be dipped while dry and hot in melted paraffin with excellent results, but it is not certain whether the surface may not retain dirt more easily."

On short lines, good insulation is of less importance than on long lines. When, therefore, the line is a short one, simple and cheap insulators may be used, and their maintenance need not be very carefully looked after; but when the line is long, it becomes necessary to employ the best kinds, and to keep them in a perfect condition. If the insulation is defective, and there are no practicable means for improving it, the resistance must be lessened. This may be effected either by using a larger wire, or by diminishing the resistance of the apparatus. A method of reducing the resistance on long lines by the use of shunts has recently been tried with good results.

Earth Wires and Plates.—The use of earth wires being to intercept leakage and to convey it to earth, it follows that they must make good earth or their effect will be rather injurious than otherwise. A good earth connection may be formed by attaching a thick wire to the pole, and coiling it in a spiral beneath the foot. When the soil becomes dry from long drought, the earth wires become partially insulated, and they do not make good earth until the ground has become damp. The evils resulting from this may, in some degree, be avoided by placing the wires deep in the ground, or in some cases, by conveying them to damp ground. From the main wire which is fixed to the side of the pole, branches of binding wire are carried to the insulators. They should be soldered to the insulator bolts or to the iron bracket holding the insulator, these brackets being provided with a tinned iron pin for that purpose. When wooden arms are used, the earth wires may be wrapped closely round them, or sunk in a saw groove. To convey the leakage through the wood, as well as that over its surface, to earth, they are screwed tightly between the head of the bolt by which the arm is fixed, and its washer. This method is, however, not so effectual as the former. If it is necessary to use earth wires on viaducts, they must be run from pole to pole and put to earth at the nearest convenient place.

The shorter the circuit, the more need there is for a good earth connection. Frequently the inefficiency of a telegraph is due to the want of such a connection. In some localities this difficulty makes itself felt more than in others, those places being especially unfavourable where the rock lies close to the surface. The plates used to form the earth connection, called earth plates, are of copper, and they should be buried in the upright position in a narrow trench, which should be filled up on each side with smith's ashes or wood charcoal. Frequently good earth cannot be obtained from a single plate, and in such a case others must be put down at distances of 20 or 30 yds. apart and connected by wires. When there are several circuits, the earth plates provided for each must be placed at such a distance apart that the resistance of the soil between them may be much greater than that of the shortest circuit. If this should be impracticable, it will be necessary to increase the resistance of the shorter circuits by means of resistance coils, otherwise the tendency to leakage from the circuit of greater to that of lesser resistance will make itself felt. When water or gas pipes are conveniently situate, they may be employed instead of earth plates. The former are preferable to the latter. Lead pipes are objectionable, for if the earth connection at one end of the circuit be a lead pipe and at the other end an iron pipe, a permanent current will be set up. For this reason, it is safer to make a connection with a pipe out of doors.

Underground Wires.—In towns it is often necessary, or at least convenient, to place a line of telegraph underground. Some years ago attempts were made to employ the system more extensively, but these attempts ended in failure. The success, however, which has attended the use of underground lines recently laid in towns shows that failure in the former case was due to bad manufacture and imperfect methods. But though an underground line, if laid now, throughout a great number of miles, would certainly be an engineering success, it would fail commercially on account of the great excess of cost over pole-work. It is not, therefore, likely that an attempt will be again made to extend the system beyond the boundaries of towns, though within those limits its adoption will probably soon become general.

The mode of laying underground wires is either to draw them into a pipe, or to place them in a kind of trough fitted with a movable cover. There are advantages attending each of these methods. The wires can be much more easily laid into the trough than drawn into the pipe, and there is also less risk of injuring them during the process; but, on the other hand, it is much more difficult to execute repairs in the former than in the latter. Pipes are more frequently employed than troughs, and they have been found in all cases to fulfil the purpose required very efficiently. They are usually laid under the flagstones, and at every hundred yards, or closer, if the line be curved, are placed oblong drawing-in boxes, 30 in. by 11 in. and 12 in. deep; these boxes are provided with lids formed of an iron frame, into which a piece of flagstone is set. To prevent rust, the pipes should be tarred inside while hot.

Each wire is usually spun over with tape. The percha and tape or hemp, if the latter be used, should be well covered with Stockholm tar and sprinkled with dry, sharp sand. Gas tar should be avoided, as its action is injurious. It has been proposed to employ bitumen instead of percha or rubber, on account of the cost of the latter substances. Bitumen insulates very well, but with the present methods of applying it, it does not appear to give satisfactory results.

The wires are sometimes put together in cables 400 yds. in length, and covered with braided hemp; but more commonly they are simply tied together in bundles. When repairs are required a new cable is connected in a loop between the sound and the faulty portions at one of the drawing-in boxes, so that the act of drawing out the old cable pulls in the new. The joints should always be made at the same part of the cable, that they may be readily found when necessary. All joints must be tested by the accumulation process, and the conductibility and insulation of each length fully ascertained both before the wires are laid and after. Indeed, almost as much care is required for a long subterranean line as for a submarine cable.

It has been found that when a buried wire becomes faulty from the conductor having become

exposed through a defect in the coating, the action of the positive current in signalling decomposes the salts contained in the soil, and forms combination with the copper of the wire. This tends to make the insulation appear better, while the negative current increases the leakage by depositing copper upon the wire and breaking up the badly-conducting mass formed by the copper current. For this reason the zinc current is always used in testing insulated wires. It may be remarked here, because the precaution is often neglected by workmen, that testing exposed pieces of covered wire should be carried on in damp weather, for in dry weather a serious fault will hardly make itself apparent upon the apparatus employed. It is also well to accustom workmen to use a sensitive galvanometer in testing, as they usually judge of the degree of leakage by the amount of deflection shown on the instrument irrespective of its sensibility. A buried wire may be tested for insulation by the tongue by ascertaining how long it will retain sufficient charge to produce a shock. It is charged by a battery, allowed to remain insulated from one to ten minutes, and then placed upon the tongue or the lips. This method is said to be extensively employed in the United States.

Testing Joints and for Distance of Fault.—The following lucid description of the methods of testing for the distance of a fault and of testing the joints in insulated wire is due to R. S. Culley.

"The methods of ascertaining the distance of a fault, measured in terms of resistance, in a cable where a wire is not broken, are as follows;—

"First, let it be supposed that a perfect earth connection exists at the fault. Then the resistance from either station measures the distance from that station; that is, if the resistance is 28, and the resistance a mile 14, the fault is two miles off. By testing from one station only, no one can know whether an earth connection has a sensible resistance or not, or what that resistance is. This test should only be used when the wire is broken, as well as to earth, and it only affords a means of roughly guessing the position of the fault.

"Second, let it be supposed that the fault is caused by an earth connection of some definite unknown resistance. In this case we may test from both stations, measuring the resistance each way, while the other end of the wire is insulated. Let these measured resistances be R and R'. Then we have the two equations,

$$\left.\begin{array}{l} x + a = \mathrm{R} \text{ where } x = \text{distance from one end} \\ y + a = \mathrm{R}' \quad " \quad y = \quad " \quad " \quad \text{other} \; " \end{array}\right\} \text{in terms of resistance.}$$

$$" \quad a = \text{resistance of fault.}$$

$$\text{and also } x + y = \mathrm{L} \quad " \quad \mathrm{L} = \text{known resistance of whole line;}$$

$$\text{hence} \qquad x = \frac{\mathrm{L} + (\mathrm{R} - \mathrm{R}')}{2}.$$

"If the resistance a remains sensibly constant, or is small compared with x and y, this will give a very good approximation. But there may not be two men capable of testing at the stations, or only one set of instruments, and then the following test, from one station only, may be employed. First, measure resistance of the line when the far end is insulated; call this resistance I. Then measure resistance with far end of earth; call this resistance e, which will be less than the previous one, and let L = resistance of line as before, then we have,

$$\text{First, } x + a = \mathrm{I}.$$

$$\text{Second, } \frac{1}{x + \frac{1}{a} + \frac{1}{y}} = e.$$

$$\text{Third, } x + y = \mathrm{L}.$$

$$\text{Hence } x = e - \sqrt{(\mathrm{L} - e)(\mathrm{I} - e)}.$$

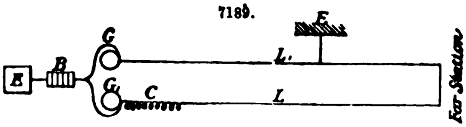
But this test also assumes a to be a constant quantity, which, unfortunately, it very seldom is. The earth connection is generally accompanied by some moisture, and the electrolysis produced by the very currents used in testing, alters the resistance of that connection.

"Hence, the following test, due to C. F. Varley, in which the resistance of the fault, whether great or small, constant or varying, does not affect the accuracy of the result, should be employed whenever possible. It can, however, only be used where a good or well-insulated return wire from the far station is available.

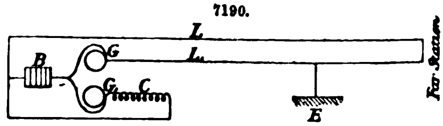
$$\begin{aligned} \text{Let } 2\,\mathrm{L} &= \text{resistance of the two lines.} \\ y &= \text{distance of fault from testing station—in resistance.} \\ x &= \text{distance from far station.} \end{aligned}$$

First make the connection shown in Fig. 7190, by which no part of the line is to earth except at fault. L' line with fault in it. L well-insulated line. Let S be the value of the coils when adjusted, so as to bring the differential galvanometer to zero, then $\mathrm{S} = 2\,x + 2\,y$, and the resistance of the fault will in no way affect this test, since the fault itself does not form part of the circuit. If the resistance of L has been determined previously, this test may be omitted.

7189.



7190.



"Then make the connection shown in Fig. 7189. Adjust the coils afresh till the galvanometer needle is brought to zero, and the resistance C then added by the coils will be such that

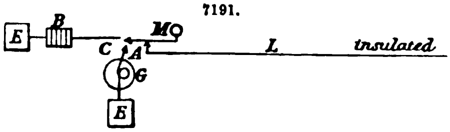
$C + y = y + 2x$, or $C = 2x$. The fault of which the resistance is unknown, is of course equally added to the two circuits in connection with the two branches of the galvanometer, and has therefore no effect on the resistance C, required to bring the needle to zero. It will be observed that $\frac{C}{S} = \frac{2x}{2(y \pm x)} = \frac{x}{L}$ expresses the fraction of the whole line, separating the fault from the distant station. It is in this way Varley uses his test; the inspector puts a handle in one position, adjusts his coils till the needle is at zero, writes down the number as denominator, moves the handle to a second position, adjusts the coils again, and writes the second number as numerator, the fraction gives the position of the fault as above; we can, however, easily if we please, calculate y in function of resistance, and obtain $y = \frac{S - C}{2}$.

"The plan of observing the numbers, and using them to form a fraction, is, however, found well suited to workmen or telegraph clerks.

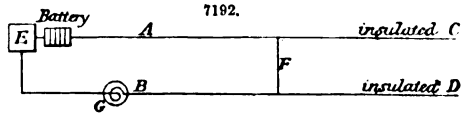
"When the line is absolutely broken, the accident must be classed under a different head. The absence of continuity does not allow any use to be made of the distant station. If the line is in perfect contact with the earth where broken, the measurement of its resistance will give the distance in function of resistance; but if the contact is imperfect, this measurement only gives the sum of the resistance due to the distance, and that due to the fault. The resistance of the fault cannot then be accurately measured.

"If the line where broken is insulated, and the line is, moreover, well insulated up to the fault, the following test, called the discharge test, gives some clue to the position of the fracture. The home end of the line A, Fig. 7191, is connected with one pole of a battery B for a little while, it is then, by a key, suddenly connected to C, one end of a galvanometer coil, the other end of which is to earth. The statical discharge induced on the wire by the action of the earth and the battery is thus discharged through the galvanometer, the needle of which is thrown more or less violently to one side; the throw is greatest on a long line, and shortest on a short line. If the line were uniform throughout, the sine of half the angle of the throw, with a given electro-motive force of the battery, would be proportional to the length of the line. The distance of the break or rupture could thus be determined, if the discharge from any known length were known; in dry weather, on a good line, this test may occasionally be used with great advantage.

7191.



7192.



"Accidental contact between wires is shown by a return current on the second line, connected as in Fig. 7192, the resistance A + B gives twice the distance if the contact is perfect. If the contact is imperfect, or is due to bad insulators, the proportion between the current starting from A, and returning to B, when C and D are insulated, gives some rough idea of the degree of importance of the defect, whether much or little. In Fig. 7192, F is the conductor connecting the two lines, and causing fault.

"We will now consider the more difficult problem, of a cable where all the wires are broken and exposed. The ordinary tests merely give a maximum distance within which the fault must lie, but this distance is never accurate within three or four miles. The following method will be correct, within half a mile, or less, if the length and resistance per mile of the cable are correctly known.

"The difficulty of the problem arises from several causes:—

"1. As the ends are exposed, they form galvanic elements or batteries, with the iron sheath and the salt water, so that a + current flows from the cable, through the testing galvanometer, to earth; this is steady and constant if the cable is not disturbed.

"2. We have to deal with two unknown resistances; that of the wire itself, and that between the exposed end and the earth; the first is constant, the second very variable, because—

"3. The action of the current alters the resistance at the point at which the metal touches the water, by coating it with substances which differ in conductibility; and at the same time the apparent resistance is still further altered by the currents of polarization set up by these substances.

"The action which takes place can be shown by placing a piece of cable in a glass filled with salt water, and applying a current from forty or fifty cells, one pole of the battery being connected to the iron sheath, the other to the copper conducting wire. The portion of the cable connected to the zinc, gives off a stream of hydrogen, while the other becomes coated with a chloride of the metal. Thus, if the negative pole is connected to the conductor, and the positive to the sheath, chloride of iron is formed, and if the connections are reversed, chloride of copper is produced.

"Let us now connect a galvanometer to the cable, in such a manner that the current from the cable battery of copper and iron in salt water, called the 'cable current,' shall deflect the needle to the *right;* the iron element being, of course, always on the earth. If a negative current is now sent into the cable, its direction coincides with that of the cable current, and does not affect the direction of the deflection. But the superior force of the testing battery overcomes the cable current, and polarizes its elements. The copper wire becomes coated with hydrogen, the iron sheath with chloride of iron, so that when the testing battery current is cut off, and the cable battery is again free to act, its action is reversed, and the needle moves to the *left*, under the influence of the current of polarization. But the hydrogen gradually enters into combination and disappears from the wire, the polarization ceases, the needle returns towards zero, passes it, and finally takes up its former position to the right, under the influence of the cable battery in its normal state. On the other hand,

if we test with copper instead of zinc, the needle is deflected to the left, the cable battery again acts as a decomposition cell, but the polarization is now in an opposite direction, the copper being coated with its chloride, and the iron with hydrogen. When the testing current ceases, the needle therefore moves to the right, and continues permanently deflected in that direction, because the normal current from the cable battery is now in the same direction as the current of polarization.

"If we apply a succession of short zinc currents, after the wire has been coated with the chloride, the needle will take up a right-hand deflection after the battery contact has been broken; but the deflection will decrease after each test, and will finally be reversed. The deflection to the right is due to the polarization set up by the chloride of copper, each application of the zinc current reduces a portion of this chloride, and assists also in removing it mechanically by the action of the hydrogen, until after a time the chloride disappears, and is replaced by hydrogen. The sign of the polarization is then changed, and the direction of the needle changed also. But there is a moment when the opposite actions of the hydrogen and chloride are apparently balanced, so that the cable battery is inert, and the end of the wire unpolarized and probably uncoated. Then, and then only, can its correct resistance be determined. The object of the special method of test is to produce this condition.

"The test for distance is best made with a differential galvanometer. First ascertain the approximate resistance in the ordinary way, and clean the end of the wire from the dirt and the salts with which it will be coated, by applying a zinc current for several hours, occasionally reversing it to get rid of any deposit of soda which may occur. The surface will be roughened by the re-deposit of the copper, which has been dissolved, and will therefore more readily throw off the hydrogen evolved by the zinc current. Next, apply a positive current for the purpose of coating the wire with chloride of copper, and finally test with the negative current. The action of the current set up by the chloride of copper will make the resistance appear less than it really is; but as the chloride is gradually reduced by the testing current, in the manner which has just been explained, the resistance will appear to increase, moment by moment, and the resistance coils must be lengthened, unit by unit, to balance the resistance of the cable, so as to keep the needle at zero, until it passes over to the opposite side suddenly, under the influence of the change of polarization, caused by the copious evolution of hydrogen, which will follow. The increase of apparent resistance, and the consequent movement of the needle, is slow and gradual, so long as the hydrogen is employed in reducing the chloride; but after the reduction is complete, and the chloride has disappeared, the increase in resistance is enormous and almost instantaneous. Unless, therefore, the resistance of the cable has been carefully balanced, so as to follow the variation of the current throughout, the test will not succeed, because the neutral condition lasts too short a time to permit the adjustment of the resistance coils.

"In any case a certain dexterity is required, which can only be obtained by practice; but fortunately the practice may be had conveniently upon an artificial fault, or a piece of percha wire in a tin can, filled with salt water, and connected to a set of resistance coils. Induction does not affect the test, and as in any ordinary cable the insulation is practically perfect, its resistance can be represented as accurately by a rheostat as by an actual cable. The higher the tension of the battery, the less does the opposing current of polarization affect the result, for its force seldom exceeds two or three cells. The measurement is therefore made with a battery of as high a tension as can be conveniently procured, sixty cells or more.

"The behaviour of a fault varies with the length of wire exposed, a short end polarizes and depolarizes very rapidly, its changes in resistance are correspondingly rapid and its resistance great. If the end is long, the changes are slower and are more readily observed; the resistance of the fault is also less.

"After having well studied the changes of the fault itself, make an artificial fault by placing a piece of the cable core in a tin can filled with salt water, and alter the length of the exposed wire until it behaves in the same manner as the cable, and then find its resistance, which will be very nearly the same as the real fault; so that the distance of the break will be the tested resistance of the cable less that of the artificial fault.

Inches of copper wire exposed ..		$\frac{1}{8}$		$\frac{1}{4}$		$\frac{1}{2}$		$\frac{3}{4}$		1	
No. of cells used		6	60	6	60	6	60	6	60	6	60
Units of line added	25	296	96	270	84	259	79	233	75	226	72
	50	325	121	299	109	287	104	261	100	255	98
	100	385	172	357	160	345	155	319	151	312	148
	150	443	223	416	211	403	205	376	202	369	199
	200	502	274	475	262	461	256	433	253	426	250
	250	561	325	533	313	519	307	489	304	482	301
	300	620	376	592	364	577	358	546	355	539	352
	350	679	427	651	415	636	409	603	406	596	402
	400	738	478	709	466	694	460	660	457	653	453
	450	796	529	767	516	752	510	716	507	709	503
	500	856	580	825	567	810	561	773	558	766	554
	1000	1440	1090	1406	1076	1392	1070	1339	1066	1332	1062

"The foregoing table was formed upon a piece of the Dunwich-Zandvoort cable, in a vessel of sea-water, and shows the manner in which the apparent resistance varies with the tension of the battery, the resistance added by the rheostat to represent the cable, and the length of the exposed wire.

"It is a convenient plan to form a table of the resistance of ends of various lengths with six and sixty cells, adding resistance by a rheostat, using the negative current and allowing the end to take up its maximum resistance. The tests with the six cells will be always higher than those with sixty, that is to say, the resistance of the end will always appear higher when tested with the lower power, and the difference between the apparent and real resistance will also increase gradually, as the length of the cable itself, or the resistance added by a rheostat increases; the length of exposed wire being constant.

"If a cable is found to give, with six and sixty cells, two results corresponding to some two in the table; it is probable that the length and resistance of the end is the same as that of the artificial fault used in the formation of the table, and therefore that the resistance between the testing station and the fault is equal to the resistance added to the artificial fault.

"So much, however, depends upon the manner in which the tests for the table were taken, or upon what we may call the 'personal equation' of the observer, that everyone should form a table for himself. The cable must be treated in precisely the same manner as the artificial fault, and therefore no table will be perfectly correct unless it is made just before the table is tested, in order that the precise manipulation may not be forgotten.

"*The Testing of Joints in Insulated Wire.*—A joint should insulate as well, or nearly as well, as an equal length of the perfect core, and the object of the test is to ascertain if this be the case. Now the leakage, even from a considerable length of good core, is too small to affect the galvanometer; but, although the electricity which escapes moment by moment cannot be measured, still if it were possible to store up the loss during a minute, and compel it to pass instantaneously through the coils, it would produce a sensible deflection.

"In order to effect this recourse is had to induction; a metallic trough, sufficiently large to contain 2 ft. or 3 ft. of the core, is suspended by straps or rods of polished ebonite, 2 ft. or even 3 ft. long. A small condenser is attached to increase its inductive capacity and enable it to store up the electricity which may leak through the percha. The testing battery, of not less than 200 cells, is insulated in a similar manner, and all loss over the surface of the conducting wires is prevented by paring their ends, so as to expose a fresh clean surface, or even by coating them with hot paraffin.

"To ascertain if the apparatus is sufficiently insulated, the trough and condenser are charged, and the swing of the needle, from an immediate discharge, noted. They are then re-charged, and left free for a time equal to that to be occupied by the test, and again discharged. The difference in the swing shows the loss in the time, and should be very small.

"The joint is placed in the trough, a negative current is applied to the cable, and the positive pole of the battery is connected to the outside coating of the condenser. Any leakage which may occur through the percha is by this arrangement accumulated in the condenser, and may be discharged through the galvanometer after any given interval.

"It is possible to find how much is lost by defective insulation during the joint test itself; but as both core and joint are subject to the same conditions, and the object is simply to see if one insulates as well as the other, this precaution does not seem to be absolutely necessary.

"To make the test. 1st. Place the joint in the trough—leave one end of the cable free; connect the copper pole of the battery to the galvanometer; connect the other terminal of the galvanometer to the trough; and, finally, charge the cable by applying the zinc pole. The charge within the cable acts inductively upon the natural electricity of the trough, the wire being in fact the inner, and the water the outer coating of a Leyden jar. A portion of the negative electricity of the water is set free, and an equal quantity of the positive is held fast or disguised by the negative charge within the cable. The free electricity is at once neutralized by the action of the battery; if it were not so arranged, it would increase the apparent leakage from the cable, being of a similar sign. The deflection or swing due to the discharge being instantaneous, it follows that if the needle *remains* deflected after the discharge, the joint is very bad, or there is leakage over the surface of the percha. The latter may be conducted to earth so as not to interfere with the test, by wrapping an earth wire round the core a few feet from the free end.

"2nd. Without disturbing the charge of either cable or trough, connect one coating of the condenser to the trough, the other coating to the + pole of the battery, the zinc being to the cable as before. Any negative electricity which may leak from the cable will now accumulate in the condenser. Allow one minute for this.

"3rd. Disconnect the condenser from the trough and battery, and discharge it through the galvanometer. If the trough and other parts of the apparatus have been well insulated, the swing will show the accumulated leakage from the portion of core under test. It is evident that these charges must be made by perfectly insulated keys and commutators.

"It often occurs when there are several wires in the cable, that the apparent leakage is greater from the joint which is first tested than from any other joints tested at the same time. This arises from the charge in the first wire acting upon the others inductively. The wires not under test should, therefore, be put to earth until they are wanted, and the condenser and trough should be perfectly discharged between each test.

"It will be understood that the results are simply comparative, not absolute; all that the method effects is to show the difference between the insulation of a joint and that of any other part of the core.

"This method somewhat differs from that ordinarily adopted. It is usual to put one pole of the battery to earth; but in this case leakage takes place over the whole cable, however long it may be. By the plan described, the leakage is confined to the part in the trough, and the whole force of the battery is concentrated there, and the apparent leakage exaggerated."

Submarine Telegraph Cables.—The nature and the construction of submarine telegraph cables are so clearly and fully described in the following extract from a paper read by Fleeming Jenkin before the Institution of Mechanical Engineers, that we need do no more than quote it here;—

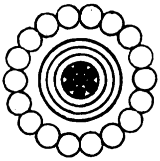
The essential parts of a submarine telegraph cable are, a conductor along which the electric

current may flow, and an insulator to surround the conductor and completely prevent it from coming in contact with the water. In selecting wire, the method followed by the manufacturers of telegraph cables is to select, by electrical test, a wire whose conducting power is about 20 per cent. less than that of pure copper.

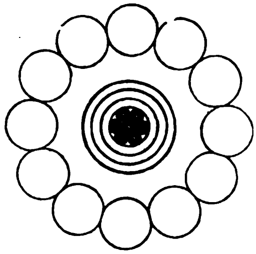
In the common cable a wire or strand of copper forms the conductor, which is covered and insulated by gutta-percha. This core of gutta-percha covered wire is served with tarred yarn, round which a greater or less number of iron wires are laid spirally, to afford longitudinal strength and lateral protection.

A cable of this class is shown in Figs. 7193 to 7195, which represent the Malta and Alexandria telegraph cable, laid in 1861, drawn full size; the copper conducting core A, Fig. 7195, is shown black in section, and is surrounded by three coatings of the insulating gutta-percha B.

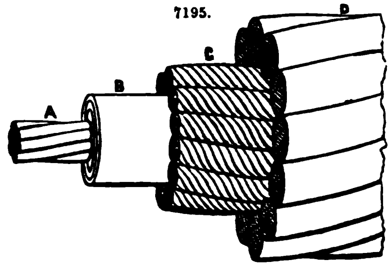
7193.



7194.



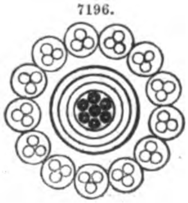
7195.



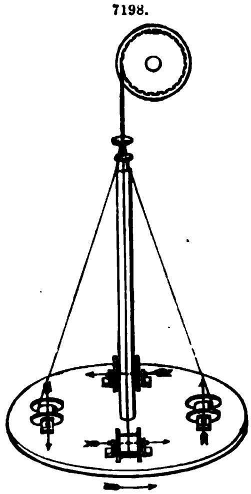
A solid wire would be preferable electrically to a strand, for the same reason that copper of small electrical resistance is preferable to copper of high resistance, the object being in all cases to obtain the greatest conducting power within a given circumference. The interstices in the strand diminish the conducting power for a given size, and the gutta-percha sheath must be of proportionately larger diameter to give the same speed of transmission and the same insulation as when a solid core of equal weight is used. When large conductors are required, however, a solid wire is not found flexible enough; and, moreover, a single copper wire is found liable to break inside the gutta-percha, without any external symptom of injury being seen; for these reasons a strand is almost universally adopted for large cores.

In the cables first made, the interstices between the wires of the strand were left vacant; but it was found that under continued pressure the water invariably penetrated into these vacant spaces and percolated along them. This was thought dangerous for various reasons, and therefore the Gutta-Percha Company now lay up their strand in an insulating compound called Chatterton's compound, consisting of gutta-percha and resinous substances, which so completely fills the spaces that a pressure of 600 lbs. a square inch cannot force a single drop of water 6 in. along the finished core; other makers have adopted the same plan. The cables, Figs. 7193, 7194, 7196, have this compound between the wires of the strand; while the Red Sea cable, Fig. 7197, and several earlier cables are without it.

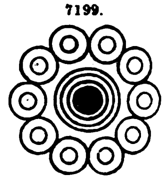
7196.



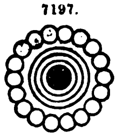
7198.



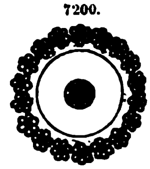
7199.



7197.



7200.

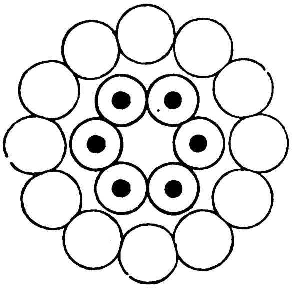


The manufacture of the copper conducting strand is extremely simple. Owing to the soft nature of the metal, it seems to be of little importance whether the wire is twisted in making the strand or not; although in the outer iron sheathing of the cable it is of special importance for the wires to be laid without twist. In the diagram, Fig. 7198, is shown a simple form of strand machine, and the twist of the wires is shown by the direction of the arrows upon the four bobbins. A friction-brake restrains the movement of each bobbin, and is adjusted by hand until the spinner feels that the tension

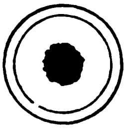
of each wire is equal. The drums of the bobbins are made large in proportion to their total diameter when full of wire, so that the leverage of the brake does not vary rapidly during the unwinding of the wire. It is important that every wire of the strand should be put in with a constant and equal strain, otherwise one wire will sometimes ruck up during the subsequent covering process, and knuckle through the insulating covering. Each length of wire is soldered to the next length, so that there may be no loose ends which might come through the gutta-percha. Where one piece of strand is joined to the next, a scarf-joint is made, lapped round with binding wire and neatly soldered.

In covering the strand the gutta-percha is applied in a plastic state, in successive coatings over the strand, which is for this purpose drawn through a series of dies, each one in succession larger than the preceding. Between the several layers of gutta-percha a coating of Chatterton's compound is laid on in the Malta and Alexandria and other cables, as indicated by the strong black lines in Figs. 7193, 7194, 7196, 7199; but the Atlantic cable, Fig. 7200, and the other cables shown in Figs. 7201 to 7204, are represented with a solid covering of gutta-percha because no Chatterton's compound was here used between the several layers of gutta-percha. The Red Sea cable, Fig. 7197, and several earlier cables had the compound between the coats of gutta-percha, though not between the wires of the copper strand; the latest cables have both.

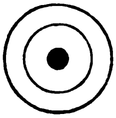
7201.



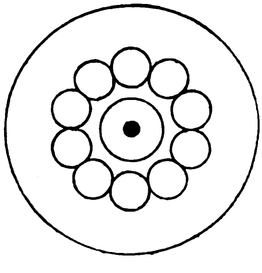
7202.



7204.



7203.



The question of the relative merits of the two materials, gutta-percha and india-rubber, for the covering of telegraph cables, is one of much practical interest. Gutta-percha sometimes contains impurities, and air-bubbles were at one time not uncommon in the covering with that material; these air-bubbles and impurities become serious faults under the action of powerful electric currents. Gutta-percha becomes plastic at about 100° Fahr., and the copper wire sometimes forces its way through the insulated sheath when the gutta-percha is accidentally softened by heat; moreover, joints unskilfully made are liable to decay in time. On the other hand, the merits of gutta-percha are very great. Not a single yard of submerged gutta-percha has ever decayed; and the importance of this fact after the experience of many years on some thousands of miles of wire can hardly be over-estimated. No gutta-percha cable has ever failed except from local imperfection or accidental injury; two causes of failure to which all known materials must be subject. The insulating properties of gutta-percha as now supplied are extremely good.

It may be remarked here that the word insulation has frequently been used in a double sense; first, as implying freedom from mechanical defect or impurity; and secondly, as implying electrical resistance. Consequently some statements that are true when the word is used in one sense have been incorrectly applied with the word in the other sense, causing some confusion in the comparisons of gutta-percha and india-rubber. Thus the circumstance that india-rubber is a better insulator in consequence of having a higher electrical resistance than gutta-percha, has in mistake been incorrectly taken to mean that india-rubber is the better material for covering telegraph cables; whereas the words better insulator imply properly in this case a superiority in the one respect of non-conducting power alone, and not a general superiority in all respects.

The defects of india-rubber differ with different makers; some kinds are liable to turn into a treacly substance on the outer surface and next to the copper; others are liable to little cracks or fissures, which appear only after the cable has been manufactured for some time; and other kinds turn slimy in water, arising it is said from a considerable absorption of water. The cause of these defects does not seem well understood, and various reasons have been assigned by different makers; such as injury of the india-rubber from heat applied to make the joint, or injury from the strain put on the india-rubber strips as they are wound on; defective structure arising in the preliminary mastication of the material in its preparation; or some injurious effect of the contact with the copper. One defect is common to all forms of india-rubber covering, namely, the necessary difficulty of making the continuous joint which is required along the whole wire; and another defect common to all forms of non-vulcanized india-rubber is the liability to injury from grease or oil. The latter danger is of the most insidious kind, for the injury is not immediately apparent, but requires a long time for its full development.

The merits of india-rubber, however, are not to be passed over lightly, and if they do not justify its general adoption as yet, they certainly entitle it to all the attention it has received for the manufacture of telegraph cables. When properly prepared it is an excellent insulator in the limited electrical sense of the word; whether better or worse than the present gutta-percha does not much matter, as has been shown above. It maintains its insulation better at high temperatures than gutta-percha, and will bear a higher temperature without permanent injury; it has also been thought by some less liable to mechanical injury than gutta-percha. But by far the most important point claimed in its favour is that a greater number of words a minute can be transmitted through a wire covered with india-rubber than through the same wire covered with the same quantity of gutta-

percha of the usual quality. There is reason to believe that in this respect india-rubber is twice as good as any gutta-percha hitherto practically supplied for cables; but a few specimens of gutta-percha have certainly been manufactured which even in this respect are on a par with the best makes of india-rubber.

The serving with hemp or jute yarns C, Fig. 7195, as practised at present, is done by machines similar to those strand machines which put a twist into the wire or yarn; and advantage is taken of the flexibility of the yarn to place the bobbins in any convenient position. A large number of yarns are used, put on with a long twist or pitch, in order to avoid any chance of bending or twisting the core if one yarn breaks or is not so taut as the others. The serving merits more attention, in the opinion of F. Jenkin, than it has received, and he considers that many machines for manufacturing telegraph cables still put too much strain upon the core, especially when it is small and weak; and that the hemp might be applied so as to protect and strengthen the core much more effectually than is now the case, and thus form a much better preparation than is now afforded for the final process of sheathing with iron wires. The usual cores, both before and after they are served with the yarn, are very weak and liable to be stretched if any hitch occurs in the feed of the machines; and it is believed that several mishaps might be traced to this cause, and that the construction of a thoroughly good serving machine is a desideratum of much importance. The yarn protected by wires remains sound under water for a long time.

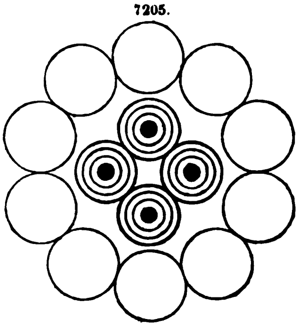
The final process of sheathing the cable with iron wire D, Fig. 7195, is similar to that of making wire rope; and the machines used for the one purpose answer for the other, with the simple addition of a guide for the central soft served core. All the machines used lay the wire without twisting it, the same as in the manufacture of wire ropes.

Instead of one gutta-percha covered core, several separately insulated wires are frequently included in one sheath, as shown in Fig. 7201, which represents a cable of this class laid in 1854 between Spezzia and Corsica. This cable and all the subsequent ones are shown full size in the engravings. This cable has six insulated conductors, which are all now in working order; and the cable has not cost anything for repairs since first laid, and is still in constant work. The several insulated wires in this and similar cables are coated with gutta-percha, and then laid up with hemp worming into a strand by laying machines similar in general arrangement to those for sheathing. The gutta-percha covered wire is of course not twisted, but the hemp generally is. The cables across the English Channel are generally of this class.

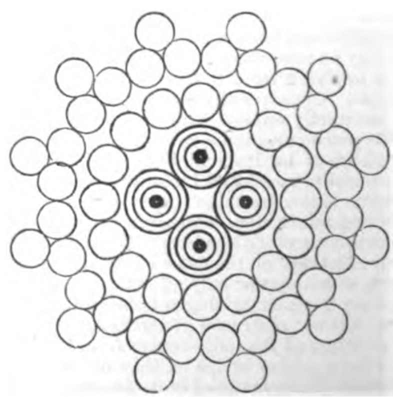
In the Atlantic telegraph cable, shown in Fig. 7200, laid in 1857, the simple iron wires of the sheath were replaced by small strands, made each of seven wires of 0·028 in. diameter; but these were found objectionable on account of their rapid corrosion.

Strands formed of thick wire are, however, frequently used to cover heavy shore-ends of telegraph cables, and are almost necessary in the largest cables for giving sufficient flexibility. Figs. 7205, 7206, represent the Holland cable, the shore end of which, Fig. 7206, weighs 19·6 tons a nautical mile; the external protecting wire is here 0·220 in. diameter in the strands covering the shore end, while the single wires covering the main cable are 0·375 in. diameter, Fig. 7205; but in the process of manufacture the cable was wound round a 7-ft. drum without difficulty.

7205.



7206.



In the Toulon and Algiers cable, Fig. 7199, laid in 1860, the iron wires of the sheath were replaced by steel wires, 0·085 in. diameter, each covered by a tarred hempen strand. This form, though convenient in many ways, has been abandoned, because the marine insects eat away the hemp with great rapidity, leaving a mere bundle of loose wires. Simple hempen coverings have also been proposed, and in a few instances unsuccessfully tried.

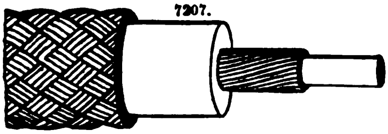
A single copper wire, however, 0·065 in. diameter, merely covered with gutta-percha, Fig. 7202, was laid successfully between Varna and Balaclava in 1855, during the Crimean war, a distance of 300 miles, and worked for about nine months.

In a construction of telegraph cable proposed by Allan, no outer covering of wires is used, but the gutta-percha covered wire is strengthened by a layer of small steel wires round the copper conductor, as shown in Fig. 7207. It is doubtful whether this plan is preferable to a simple copper strand covered with gutta-percha; though superior mechanically, it is far inferior electrically.

The rapid corrosion of the outer wires in some situations when submerged is perhaps the chief defect of the common type of submarine cable. To prevent this corrosion, the Isle of Man cable,

shown in Fig. 7203, and the Wexford cable, had a bituminous compound applied over the iron wires on Latimer Clark's plan. The Isle of Man cable was passed through the hot melted compound, and was considered to have been injured in some places by having been accidentally delayed in its passage through the hot material. The Wexford cable was not passed through the melted mass, but had the compound thrown over it or basted on, and by this simple contrivance a very serious danger was avoided. This plan of preventing the decay of the iron wires is fast coming into favour.

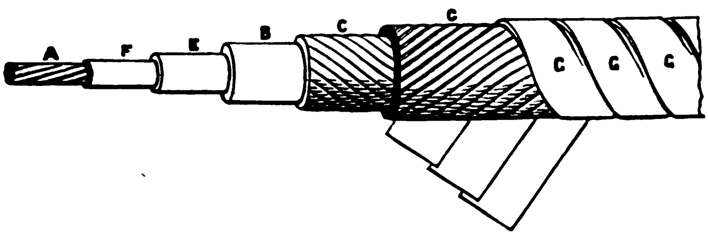
7207.



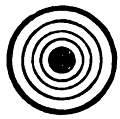
As a protection against rust it has also been proposed to cover each of the outer wires separately with gutta-percha. A cable of this make, shown in Fig. 7196, with strands composed of three iron wires instead of single wires in the sheath, was suggested by Chatterton for the new Atlantic line, and except on the score of cost seems well adapted for the purpose. It has also been proposed to protect the iron wires by vulcanite, applied either as a general coating or to each weir separately.

In a plan introduced by Siemens, instead of protecting the iron wires they are omitted altogether, and another material considered more durable is substituted. This construction of cable is shown in Figs. 7208 to 7210. The core is surrounded with two layers of hempen strands C, C, Fig. 7208, laid on under considerable tension. Three or more strips of copper or brass G, G, about 0·01 in. thick, are then bound round these strands while they are still stretched by the tension; and this copper or brass sheathing grips the hempen cords tightly, so that they cannot contract longitudinally after leaving the machine. By this construction a cable is obtained which is extremely light and strong; thus a cable ⅜ in. diameter bears a strain of 15 cwt. before breaking, and stretches only 0·8 per cent. of its length under a load of half the breaking strain.

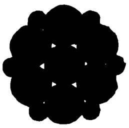
7208.



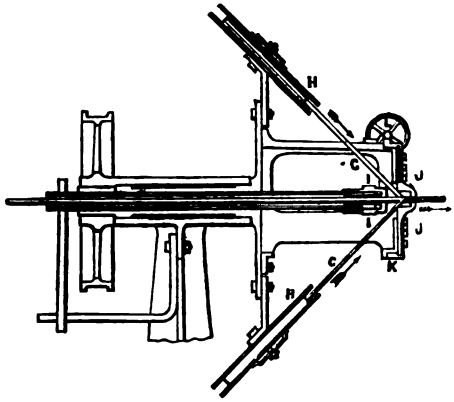
7209.



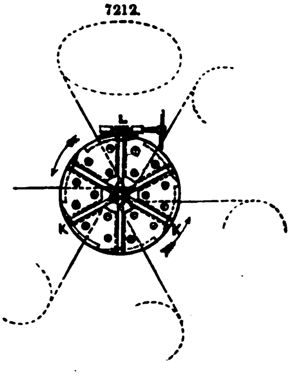
7210.



7211.



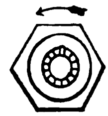
7212.



Figs. 7211, 7212, are of the machine used for sheathing the cable with the metal strips. Two serving machines are placed one behind the other, and are driven in opposite directions, laying on two distinct hemp coverings. The number of bobbins or the size of the strand in the two machines is so adjusted that each covering, although of different diameter, may have the same lay or pitch of the spiral. Each hemp strand passes round a V pulley between the bobbin and the laying plate, and an adjustable brake is applied to each of these pulleys to strain or stretch the strands. A cable of ⅜ in. finished diameter has two layers of 16 hempen strands each, and each strand is laid on under a strain of 8 lbs. In front of the two serving machines, and driven by a separate band, stands the sheathing machine, Fig. 7211. The copper or brass strips G, G, are wound on bobbins H, as in the usual serving machines; and are drawn off from the bobbins to certain guides of peculiar form close to the served core. These guides lead the several strips so that each strip laps over the preceding one by about one-third of its breadth. The core is supported and compressed by the tightening nozzle I I up to the very spot at which the metal strips are laid on. The nozzle I is made up of segments contracted by an adjusting screwed nut, a transverse section of which is shown one quarter full size in Fig. 7213. The strips laid on

lapping over one another would form a cone instead of a cylinder, if it were not for a series of rollers J, J, between which the metal-sheathed cable is immediately passed. These rollers forcibly compress the metal sheathing into a cylindrical shape; and a simple adjustment regulates the pressure exerted by all the rollers, as shown in the end elevation, Fig. 7212, by means of circular inclined surfaces K pressing upon the ends of the slides that carry the rollers, which are all adjusted simultaneously by the hand-wheel L. The result of the manufacture is certainly a cable very beautiful in appearance; its practical value can only be decided by experience.

7213.



The copper or brass sheathing affords lateral protection to the core; the longitudinal strength of the cable is amply sufficient both for the necessary strain during submergence, and to provide against accidental injury; and insects will not lodge in the hemp so long as the metal sheathing remains intact. There may be some ground for apprehension as to the durability of the light copper or brass sheathing; but this must necessarily be left to be decided by further experience on a large scale.

In reference to the defects of the usual iron-wire sheathing as shown in the drawings, it may be observed that some misconceptions have existed upon the subject. It seems to be generally supposed that wires laid on spirally round a soft core must, as soon as any strain comes upon them, stretch somewhat in the way that a spiral spring does; and many attempts have been made to obviate this supposed defect; but on actual trial no defect is observed. The single open helix of a spring stretches by diminishing the diameter of the coil; but when a number of wires are laid up touching one another, so as to form a solid ring or cylinder round a centre, as in a telegraph cable, the diameter of the ring cannot diminish, even though the centre of the cable is soft; and consequently the only stretching that occurs is due to the elongation of the iron itself, added to a very small constant, due to the more perfect closing of the wires one against another. The following experiment on the stretching of telegraph cables is taken at random from a very large number made by the Board of Trade Committee on submarine telegraph cables, all confirmatory of this view. The total section of iron in the Red Sea cable which was experimented upon, shown in Fig. 7197, is about $\frac{1}{10}$ sq. in.; and one sample 100 in. long elongated 0·56 per cent. with 75 cwt. strain; and it broke with 77¼ cwt., or about 39 tons a square inch strain upon the iron wire. Other samples of the same cable elongated about 1 per cent. with 85 cwt. Then single iron wires of about the same size as those in the cable, 0·085 in. diameter, were found to stretch from 0·46 to 0·72 per cent. before breaking, and bore about 4·4 cwt. each, or 39 tons a square inch. It appears therefore from experiment that there is hardly any difference in elongation between a solid rod and a well laid-up cable; and in strength no difference whatever between the cable and the wire composing it. The core does not, as at present made, add sensibly to the strength of the cable; for its resistance to the extension of say 1 per cent., at which the cable breaks, is insensible compared with that of the iron-wire sheathing.

The twist put into a cable by the usual mode of coiling it when laid in a mass, as in the hold of a vessel, has also sometimes been misunderstood: a twist is no doubt put into the cable by the process of coiling, but this twist is as certainly taken out again when the cable is uncoiled, and is therefore of no importance.

The only inconvenience attending the spiral lay of the cable sheathing is first apparent when the cable is being paid out, without sufficient strain upon it to lay it taut along the bottom. Then as the slack accumulates the cable becomes virtually free at the bottom, while the parts near the surface of the sea have considerable weight to bear; and the cable therefore untwists and throws itself over into a bight. The number of turns taken out of the cable, and of bights put into it along the bottom, depends simply on the amount of slack paid out. When the cable is again picked up, these bights draw tight into kinks, to the injury of the recovered cable; and this is the only practical inconvenience attending the usual spun cables. The amount of elongation consequent on the untwisting is quite insignificant; and, except for these kinks, a telegraph cable recovered after three years from 1500 fathoms depth has been found just as good as when it was laid out.

The common iron-covered cable can be easily laid safely in depths not exceeding 1000 fathoms; but beyond that depth steel wire should be used for the sheathing, or the specific gravity of the cable diminished. Exposed hemp is not admissible, owing to the marine insects already mentioned, which are found at all depths.

The manner of laying a telegraph cable and the machinery requisite for carrying out the operation, are matters of the first moment to the telegraph engineer. The experience gained in laying the Atlantic cables, and especially the failures that attended the first attempts, have led almost to perfection in the machinery for paying out, as well as to the invention and successful application of other machinery for recovering a cable after it has been laid. The following succinct and clear description of such machinery is given by George Elliot in a paper read before the Institution of Mechanical Engineers.

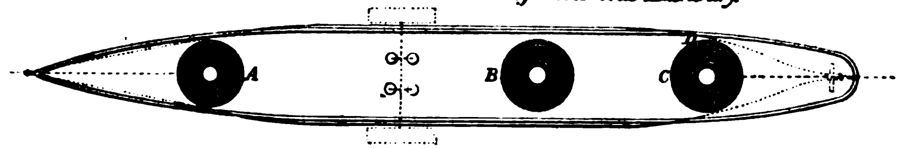
The Atlantic Telegraph Cable Expedition of 1866 was twofold in its purpose, the first object being to lay a new cable, and the second to recover and complete the one commenced and lost in the unsuccessful attempt of the previous year.

The cable itself was coiled in three circular wrought-iron tanks, which were built on the main deck of the ship, as shown in Figs. 7214 to 7216, which represent a general plan and longitudinal and transverse sections of the vessel. The foremost tank A occupied the space which had previously been the forecargo space; and the after tank C was placed in what had been the aftercargo space. The middle tank B occupied what had been the second dining saloon; and the funnel (shown by the dotted lines in Fig. 7215) from the pair of boilers in that position was removed for the purpose, those boilers being thrown out of work during the expedition. The whole of the fittings in these spaces had been removed, and each of the tanks was stayed to the sides of the ship by two flat frames of iron, built on angle-iron framing, thus securing the tanks in the most sub-

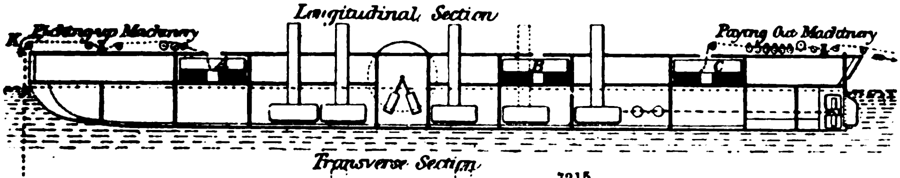
stantial manner. The deck had also been shored underneath by balk timbers, which were carried through from deck to deck down to the bottom of the ship.

7214.

Plan of Great Eastern containing Cable and Machinery.

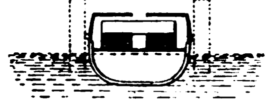


Longitudinal Section.



7215

Transverse Section.



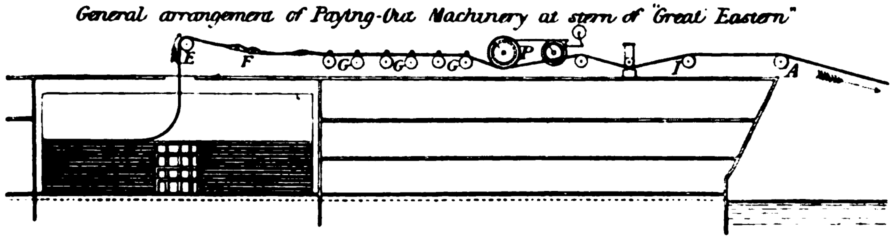
7216.

The fore tank was 51 ft. 6 in. diameter, the middle tank 58 ft. 6 in., and the after tank 58 ft.; they were all of a uniform depth of 20 ft. 6 in., and similarly constructed in all respects. The bottoms were ½ in. thick, lap-jointed; and the sides were ⅜ in. thick in the lower half, and ½ in. in the upper half. The sides were butt-jointed, so as to present a perfectly smooth surface inside; and the bottoms were covered with a thin wood floor to receive the cable. As it was of vital importance that the cable should be kept always under water, to prevent depreciation of the gutta-percha coating, and also to afford the only means of effectually testing its electrical condition, these tanks were carefully made water-tight. In paying out the cable, the water in the tanks was kept somewhat below the level of the top flake, and required to be lowered during the paying out; for this purpose each tank was supplied with discharge-valves, and as the bottoms of the coils were above the water line of the ship, Fig. 7215, it was only necessary to open these valves in order to allow the tanks to discharge themselves completely.

The coiling of the cable into the tanks, out of the hulks by which it was brought from the Telegraph Construction and Maintenance Works at Greenwich to the Great Eastern at Sheerness, was effected in the following manner. The cable was brought up over the side of the ship from the hulk, upon wheels which guided it on to a large deep-grooved wheel driven by steam power; on the tread of this wheel ran a small jockey-wheel or roller, pressing the cable down into the groove of the large wheel, so as to give sufficient friction for enabling the wheel to draw up the cable from the hulk. The coiling commenced from the outside of the tank, the end being previously triced up above the tank, leaving a clear end for splicing and testing. The first turn of the cable was carefully laid round the outside of the tank, and the next was laid back close up against the previous turn, and so on until a perfectly flat flake or layer was laid into the eye of the coil, which was left about 9 ft. 6 in. diameter. The cable was then led out direct to the outside of the tank, across the coils already laid; and another flake was commenced precisely similar to the first, this process being continued until the tank was filled. The direction of lay-out of the cable from the end of one flake to the beginning of the next was tangential to the circle of the eye of the coil, as shown at D in the plan, Fig. 7214; and the portion of cable crossing the coils was protected from the weight of the coils above by wood battens laid on each side of it, about 3 in. wide and 1 in. thick, with the edges rounded. When the coiling down of the cable into the tanks was finished, eyes were fitted into the centre of each coil, which were telescopic in their construction, so that as the cable was paid out the eyes could be lowered from time to time. Men were stationed in the tanks for the purpose of keeping the cable always clear during the paying out.

7217.

General arrangement of Paying-Out Machinery at stern of "Great Eastern."



In paying out the cable it was passed up to the hatch over the centre of the coil, and carried over a large wheel E about 4 ft. diameter, as shown in the enlarged longitudinal section, Fig. 7217.

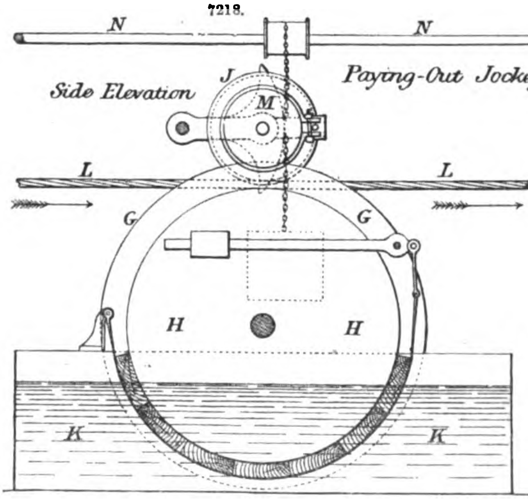
The cable was then carried in a trough F about 2 ft. wide, made of sheet iron, leading to the paying-out machinery; this trough was fitted with rollers at about 10 or 12 ft. intervals to relieve the cable from friction in passing along, until it reached the paying-out machinery, which was placed in the stern of the ship, slightly to the port side.

The length of cable in the after tank was 840 knots (1 knot = 6084 feet = 1·15 statute mile), in the middle tank 865 knots, and in the fore tank 671 knots; and the entire length of 2376 knots was joined up into one continuous length of cable before the laying was commenced. The size of the cable was $1\frac{1}{8}$ in. diameter, and its weight 31 cwt. a knot in air, and $14\frac{3}{4}$ cwt. a knot when immersed in water; the breaking strain was 8·10 tons, equal to eleven times its weight in water a knot, so that the cable would just bear its own weight in 11 knots depth of water.

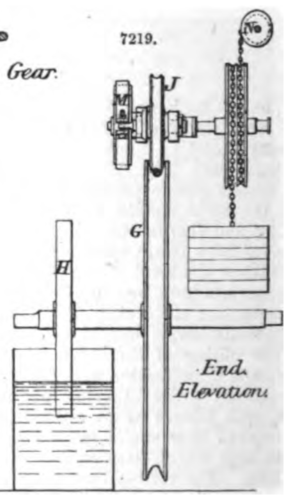
Paying-out Machinery.—In the paying-out machinery the chief object to be attained was to supply some means of checking the cable in the most regular manner possible while passing out of the ship, and also of keeping it in a state of constant tension; and it was required that the amount of this tension should be at all times known, and that it should be regulated by the depth of the water in each particular part of the ocean, and also to some extent by the speed of the ship.

The most important feature is the arrangement by which it was rendered impossible that more than a certain strain should be kept upon the cable during the paying out. A less strain would only involve a slight loss of cable; but any increased strain might possibly damage or even destroy it. The cable on entering the paying-out machinery was passed over a series of six deep-grooved wheels, each about 3 ft. diameter, one of which is shown in side and end elevation at G in Figs. 7218, 7219. On the shaft of each wheel G was fixed a friction-wheel H of the same diameter,

7218.



7219.



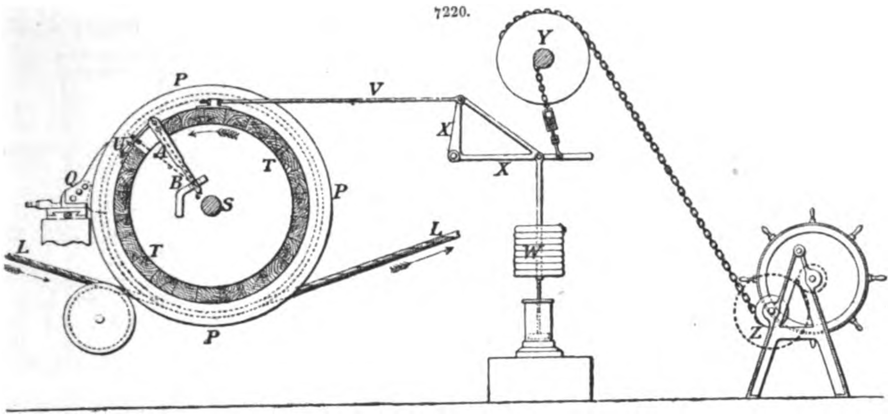
to which was fitted a friction-strap lined with wood and tightened by a weight on a lever; to prevent any unnecessary wear, this friction-wheel ran in a tank of water K. Above each of the grooved carrying wheels was a jockey-wheel J about 14 in. diameter, pressing the cable L down into the groove of the carrying wheel G, and hooped with an india-rubber tire to form a soft cushion, so that no damage might be done to the cable. The jockey-wheel was also fitted with a small friction-wheel M having a wrought-iron strap adjustable by a screw. Any one of the jockey-wheels could be lifted up, so as to allow the cable to slip freely through the groove in the carrying wheel; or in case of necessity the whole set of jockey-wheels could be raised at once by a large hand-wheel, like an ordinary ship's steering-wheel, turning the longitudinal shaft N, which lifted up each jockey-wheel by a chain winding upon the shaft. In practice there were generally about four of these wheels kept at work, but the machine was made with six in case of need.

After the cable had passed through this part of the machinery, called for distinction the jockey-gear, and had thereby been subjected to a slight amount of strain, it was led to the main paying-out drum P, shown in side elevation in Fig. 7220, and in end elevation in Fig. 7221. The cable L entered on the under side of the drum, Fig. 7220, and was passed four times round, as a rope is passed round a capstan, and for the same purpose of getting a firm hold upon it. Just above the point at which the cable was led on, a knife-guide Q was placed for fleeting or slipping sideways the coils already on the drum, so as to leave a clear lead-on for the fresh cable; this guide was adjustable in both directions with screws, like a slide-rest on a lathe. The shaft S of the drum was carried through on each side, one end being fitted with a coupling R, which will be referred to afterwards in connection with the picking-up arrangements adapted to this machine; and on the other end were fitted the main friction-brakes T, T.

These self-adjusting friction-brakes were invented by Appold, and it is interesting to note that they were the identical brakes used in the first attempt to lay the Atlantic cable in 1857. The brake-wheels themselves T, T, Figs. 7220, 7221, of which there were two on the shaft, were 4 ft. 6 in. diameter, and 12 in. wide on the tread, which was turned a little convex. On each

wheel was fitted a wrought-iron strap, lined with wood, and a screw adjustment U admitted of any required amount of friction being obtained. On the top of each brake-strap was a lug, to

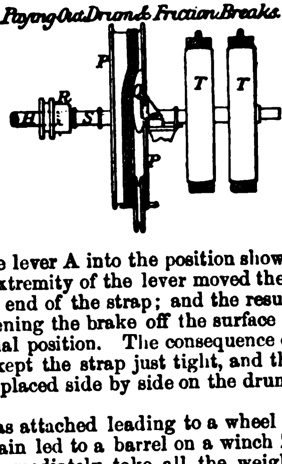
7220.



which a long rod V was fastened, leading to the top of a bell-crank lever X with arms in the proportion of 1½ to 1; and to the long arm of this lever was suspended a rod carrying a number of weights W, which were removable at pleasure for adjusting the strain. The rod was continued below the weights, and had a piston attached to it working loosely in a water-cylinder, to prevent any sudden jerking action from coming on the brake. By screwing up the adjustment U, the brake was made to have sufficient friction for lifting the weights on the suspension-rod.

7221.

End Elevation of Paying Out Drum & Friction Breaks.



In order to render the brake self-adjusting, so that it should relieve itself whenever binding too hard, the brake-strap was cut through, and the ends were attached to a lever A in the manner shown in Fig. 7220, the lower extremity of the lever being free to move in a slot cut in the stationary bracket B. When the brake was binding too hard, so that it began to lift the weight W too high, the brake-strap consequently travelled round and brought the lever A into the position shown dotted. The attachment of the one end of the brake-strap at the extremity of the lever moved then through an arc of a larger radius than the attachment of the other end of the strap; and the result was therefore equivalent to lengthening the brake-strap and slackening the brake off the surface of the wheel, causing the weight W to fall back instantly to its original position. The consequence of this action was that when the brake was at work the lever A kept the strap just tight, and the weight W continued just oscillating. The two brake-wheels T, T, placed side by side on the drum-shaft, Fig. 7221, were both fitted alike throughout.

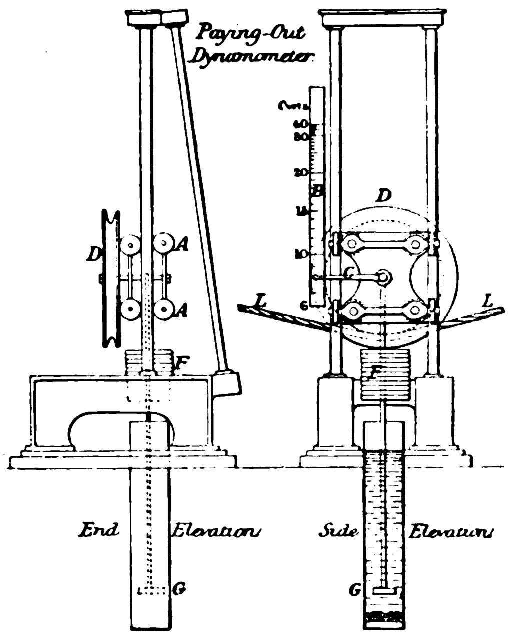
Near the end of the bell-crank lever X, Fig. 7220, a chain was attached leading to a wheel Y overhead; and from a larger wheel on the same shaft another chain led to a barrel on a winch Z. A man standing at this winch by turning the hand-wheel could immediately take all the weight off the brakes T, T. The whole of this paying-out machine was made double, so that in case of any mishap there might be no delay, but the cable might at once be removed from one drum to the other. This provision, however, fortunately proved to be needless, as throughout the expedition there was no failure in any part of the machinery, its action having been in every particular perfect.

The cable having by these means been sufficiently checked was passed over the stern wheel A, Fig. 7217, into the sea; and on its way the actual strain was measured by a dynamometer placed at D, consisting of the following arrangement. Immediately on the cable leaving the paying-out drum P it passed over a wheel H, and at a distance of 23 ft. 6 in. over another similar wheel I; and in the centre between these two wheels the dynamometer D was fixed, which is shown in Figs. 7222, 7223. It consisted of a wheel D, weighted to a particular amount, and riding upon the cable L, being guided in a fixed vertical frame by rollers A, A. The amount of deflection evidently varies according to the strain on the cable, and the strain was calculated from the formula obtained by the ordinary resolution of forces, namely, $S = \frac{l}{4d} W$ approximately; where S = strain, and W = weight of dynamometer wheel D, both in the same terms; l = distance between centres of carrying wheels H and I, Fig. 7217; and d = deflection of cable. The values of d or amounts of deflection were calculated for all strains from 7 cwt. up to 40 cwt., and a scale B was affixed to the instrument with an index C carried upon the wheel D; so that the strain could immediately be read off at all times by simple inspection. The total weight of the wheel D and its suspended weight F was 426 lbs., and the rod carrying the weight F was continued down to a piston G working freely in a cylinder of water, to prevent any sudden jerks of the dynamometer. The ordinary strain in paying out was found to vary from 10 to 12 or 14 cwt., and at no time exceeded 16 cwt.

The paying-out drum was also supplied with steam power for reversing its action and picking up the cable, should any fault occur requiring such an operation. This constituted one of the most important improvements over the arrangements of the 1865 expedition, in which it had been

necessary to hand the cable along the side of the ship from the paying-out machinery in the stern to the picking-up machinery in the bow, on any occasion of requiring to haul in the cable; and it was during this hazardous process that the cable was broken and lost. In the present machinery the shaft S of the paying-out drum P, Fig. 7217, was prolonged on one side for the purpose of forming a coupling to the picking-up arrangement. It was considered advisable to make all this part of the machinery sufficiently strong to work with, and if necessary even to break the large grapnel-rope, which had a breaking strain of more than 30 tons. The shaft S was therefore made in its smallest place 7½ in. diameter. There were three points to be specially considered in the design; first, that the moving parts of the machine should be kept as light as possible so that the momentum of the moving mass in paying out should be as small as possible, and should therefore strain the cable as little as possible, either in case of any sudden and accidental mishap, or when the ship was pitching; and this was of vital importance. Second, that the picking-up arrangement should be capable of being brought into action at a moment's notice. And third, that the strength of the machine should be sufficient to cope with a rope having the uncommon breaking strain of 30 tons. These various requirements were admirably met by the arrangements adopted in accordance with the designs of Clifford, the engineer of the Telegraph Construction and Maintenance Works, who had also worked out the design of all the machinery employed in the expedition.

7222. 7223.



In order that the machinery for paying out might be as light as possible, the picking-up motion was coupled direct to the shaft S of the drum itself, as in Fig. 7221; so that when the coupling was thrown out, the paying-out machine remained intact and as similar as possible to what would otherwise have been necessary if there had been no picking-up arrangement. This shaft and coupling had to be of the great strength necessary to bear a torsional strain of 30 tons, acting at a leverage of 2 ft. 8 in. The shaft ends were squared, and a large wrought-iron coupling R capable of sliding along coupled the two shafts securely; and the application of this was the work of a moment. On the shaft H thus coupled to the drum-shaft was fixed a large spur-wheel of 7 ft. 11½ in. diameter and 5 in. pitch: this pitch may at first appear excessive, but it is less than is in use for such exceptional strains. A train of gearing driving the pinion working into this wheel admitted of a ready alteration in speed and power, and was driven by a pair of trunk engines made by Penn, having a nominal horse-power of 80, but working in this case considerably below that power, as the condensing part of the engine was dispensed with, and the steam supplied by the ship's boilers was only 20 lbs. pressure. The whole of the spur-gear was supplied by Jackson of Manchester, and was manufactured by their wheel-moulding machinery, which secured a remarkably true bearing surface on the teeth. The steam was conveyed to the engines by an 8-in. copper pipe of about 130 ft. length; and as a considerable condensation was anticipated from such a great length of pipe, a separator and superheater were fitted close to the engines, so that they received their steam in about an ordinary condition.

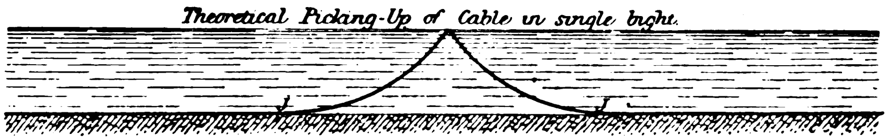
In paying out the cable the portion in the after tank was first taken, in order to trim the ship, as she was considerably by the stern at starting; the fore tank was next emptied, and the middle tank left to the last, the ends of the cable from the several tanks having been spliced together originally in that order of connection. When each tank became nearly empty the ship was slowed down, and it was quite stopped for a short time whilst the paying out of the cable was transferred from one tank to another. This apparently rather delicate operation was effected on both occasions without difficulty. The whole of the cable in the three tanks was spliced up into one length before the paying out commenced; and the length between each tank was carefully laid in troughs of wet saw-dust, so that it could be kept under electrical test; it was also from time to time thoroughly soaked with water. The total length of cable paid out was 1851 knots, and the time from shore was fourteen days, giving an average of 132 knots a day paid out, and an average rate of 5½ knots an hour for the cable. The total distance run was 1669 knots, making the average proportion of slack paid out 11 per cent.

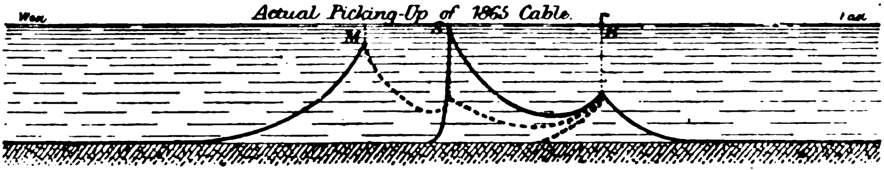
During the whole time of the paying out, the machinery was most carefully watched at all points. The drums were fitted with rotometers, showing the amount of cable which had been paid out; and this amount was carefully noted every fifteen minutes in the ship's log, and the speed of paying out and the speed of the ship were calculated so that a right amount of slack might be allowed. If the ship were travelling too fast, the speed was immediately reduced in the engine-room; and if too much cable was being paid away, a small addition to the weights on the drum

brakes usually remedied this defect speedily. Varying winds and currents and many other circumstances caused constant watching from moment to moment to be increasingly necessary.

Picking-up Machinery.—The cable of 1865 had been laid with about 15 per cent. of slack, and this percentage of slack was the great source of hope for the successful recovery of the cable. It was calculated that if the cable could be raised to the surface, without hooking it at more than a single point, there would be a bight suspended in the water of 9¼ knots in length, when in 2 knots depth of water, as in the diagram, Fig. 7224; and the horizontal distance J J would be 8 knots

7224.



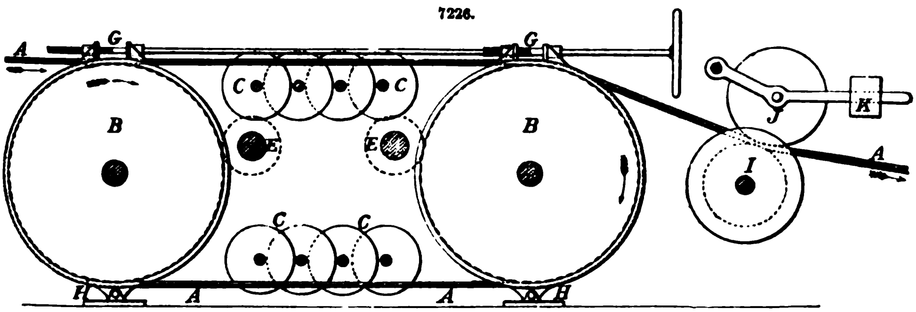


7225.

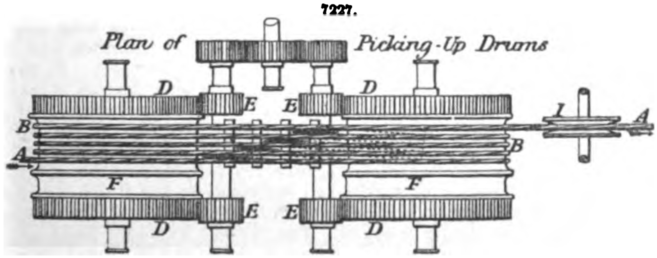
between the portions resting upon the ground, giving an excess of length of 15 per cent. in the suspended bight; and the results of the actual picking up proved this calculation to represent very closely the curve of the suspended cable. The size of the cable was 1⅛ in. diameter, and its weight 35¾ cwt. a knot in air, and 14 cwt. a knot when immersed in water; the total weight of a suspended length of 9¼ knots in water was therefore 6½ tons, but as the breaking strength of the cable was 7¾ tons, it would carry the weight of 11 knots of its own length in water before breaking. As, however, the possibility of its recovery in this manner in a single bight was generally considered to be out of the question, it was intended therefore to attempt raising it by degrees only. Three steamships were accordingly fitted with picking-up apparatus, the Medway, Great Eastern, and Albany, for the purpose of grappling for the cable simultaneously in three places; the Medway to grapple to the east and the Albany to the west of the Great Eastern.

The picking-up machine was very powerful, as it had to cope with a rope of 30 tons breaking strain, and if necessary to break it. It is shown in elevation and plan in Figs. 7226, 7227. The

7226.



7227.



two large drums B, B, each 5 ft. 8 in. diameter, were fixed on shafts parallel to each other at 11 ft. distance apart from centre to centre. The grapnel-rope A A was passed four times round these two in the manner shown in Fig. 7227, passing away on the opposite side from where it entered on. The fleeting of the rope was effected by small disc rollers C, C, placed on shafts between the drums, four above and four below; and each part of the rope was fleeted after leaving one drum before it entered on the other, thus keeping every portion of the rope clear of the rest. The fleeting required much

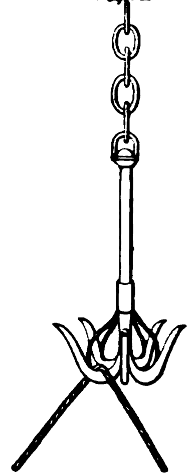
more care in this machine than in the one for paying out, as the shackles and swivels on the grapnel-rope would capsize on and hold down the preceding coil of the rope on the drum, unless the four coils were all kept very wide apart.

As the strains to which it was expected the machine might probably be put were very great, it was thought advisable not to take the power through the shafts of the drums B, B; and accordingly the drums had spur-wheels D, D, fixed at each side, into which the pinions E, E, geared; and by this means no torsional strain whatever was put on the shafts of the drums. The strain of the grapnel-rope was divided thus between four spur-wheels, and the pitch of these was only 4 in.; although in the paying-out machine, where this division of strain could not be effected, the spur-wheels were 5 in. pitch. Each of the drums had a brake F fixed to it, and both the brakes were worked by one shaft G G, with two screws on it, carried fore and aft along the machine over the brakes. All the strain of the brakes was carried by brackets H, H, on the sole-plate, and in no way by the screw-shaft G; and this is believed to be rather a novel application of the brake-strap, and may be worthy of remark.

The grapnel, Fig. 7228, was simply a very large ordinary boat grapnel, made with five prongs instead of three; it stood about 4 ft. high, was fitted with a swivel at the top, weighed about 2½ cwt., and its prongs would carry a strain of about 8 or 9 tons without damage. Shackled to this was a 15-fathoms length of 1¼-in. chain, to which was fastened the grapnel-rope. This rope was a most remarkable one, being 1¼ in. diameter, and consisting of seven strands, six strands round one; each strand again consisted of six smaller strands of hemp, in the centre of each of which was a wire about $\frac{1}{10}$ in. diameter. The rope was repeatedly tested, and was never known to break with less than 30 tons strain. Its weight in air was about 5 tons a knot, and in water 3¼ tons.

7228.

Grapnel



At the bow of the ship were fitted four iron girders carrying three cast-iron sheaves about 3 ft. 9 in. diameter; these sheaves were all clear of the ship, and over the centre one the grapnel-rope was led on board, as shown at K, in Fig. 7215. The grapnel-rope was led directly to the picking-up machine from the bow sheave, passing through a dynamometer, so that the strain could be ascertained at all times. This dynamometer was similar to the one for the paying-out machinery described before, except that it was of a much heavier construction and loaded with a weight of 2142 lbs. The vertical travel of the dynamometer wheel was 5 ft., the horizontal length of deflected cable 30 ft., and the graduations of the scale ranged from 2 tons to 20 tons.

The machine was driven by a pair of trunk engines, precisely duplicates of the pair employed in the paying-out machine; and these engines, together with the picking-up machine itself, were made by Penn. There was also a system of gearing similar to that belonging to the paying-out machine, for admitting of a change of speed and power; the slowest speed, when the engines made 80 revolutions a minute, was about ⅜ knot an hour, and the quickest about 1½ knot an hour. The machine was supplied with a draw-off wheel I and jockey-wheel J, having an adjustable weight K, so as to keep the grapnel-rope A well taut on the drums B; and a rotometer was added for measuring the length of grapnel-rope overboard. When the picking up of the cable was in progress, the grapnel-rope was delivered from the picking-up drums into the fore tank, which was at that time empty.

The process of grappling was as follows. The exact line of the cable having been marked by a couple of buoys, put down by nautical observation, the ship was brought into a position about 3 or 4 knots north or south of this line, according to the direction of the wind and current, so that the ship might be drifted slowly across the line of the cable. The new cable of 1866 had been laid at a distance of about 30 knots southward of the line of the old cable, so as to avoid all risk of injury in the process of grappling for the old cable. In a depth of 1900 fathoms, nearly 2 knots, about 2200 fathoms length of grapnel-rope, with the chain and grapnel as before described, was lowered with great care, taking about an hour or an hour and a half for the purpose. Whilst the grapnel was being lowered, accurate observations were continuously taken of the indications given by the dynamometer; and the grapnel striking the bottom, was almost immediately indicated by a diminution of weight, as it and the chain weighed rather more than half a ton. About a couple of hundred fathoms of additional rope were then paid out, and the dynamometer from this time was most strictly watched; averages of the indications were taken every few minutes, and many hours frequently passed before there was the smallest change in these averages. It was interesting to observe how steadily these averages remained at about 8½ to 9½ tons, dependent upon the length of grapnel-rope out, and the strength of the wind and current. An indicated rise of 5 cwt. was generally considered satisfactory evidence that the cable was once more hooked, and this seldom proved wrong; no attempt, however, was made to haul in the rope until the strain rose 2 tons above the average. As soon as a strain of 10½ to 12 tons was observed, the ship was brought up by her engines to ease the strain, and the operation of picking up commenced; the strain then generally rose to about 14 or 15 tons, and continued at this amount until the bight of the cable was raised off the ground, after which time it gradually lessened. The attempt was once made to raise this bight direct to the surface without assistance from the other ships, and it proved successful, the cable coming a few feet above the water with a strain of about 6¼ tons. There was, however, a heavy swell on at the time, and the pitching of the ship broke the cable through.

After many ineffectual attempts, the cable was at length successfully raised in the following manner. It was hooked by the Great Eastern, and the bight being raised about 900 fathoms from the bottom was buoyed there, as shown at B in Fig. 7225; the buoy attached was of the largest size, weighing 3¼ tons, and capable of supporting a weight of 13 tons. The Great Eastern then again grappled for the cable about 3 or 4 knots westward at S, and again found it; the Medway

found it at the same time at M, about 2 knots westward of the Great Eastern. The Great Eastern then commenced hauling in, signalling to the Medway to do the same, and to break it if she could not bring the bight to the surface; this she accordingly did, the cable breaking about 200 fathoms below the surface. The Great Eastern in this manner had a loose end of about 2 knots to the westward, and had immediately a much reduced strain to contend with. Ultimately the end was successfully brought on board, the electrical circuit to Valentia was once more established from the ship, and the movement of the small speck of light on the galvanometer scale by the current received from Ireland indicated the success of the undertaking.

See Battery. Boring and Blasting. Cable. Rope-making Machinery.

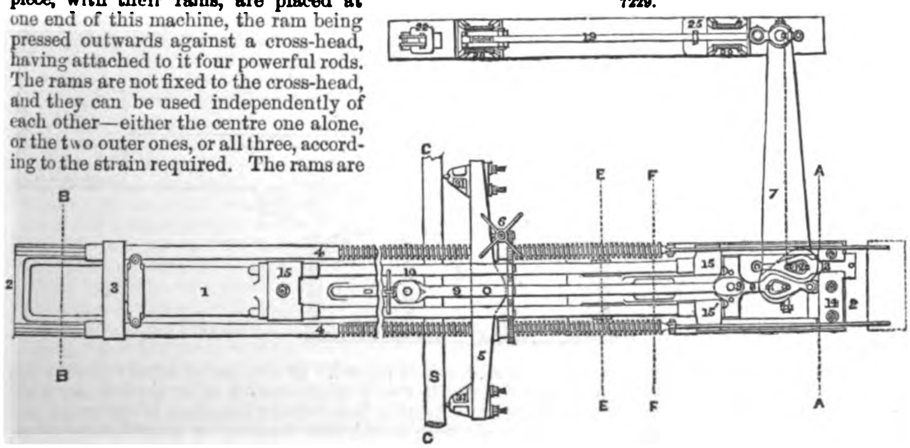
Books on Telegraphy;—Faraday (M.), 'Experimental Researches in Electricity,' 3 vols., 1839–55. Shaffner's (T. P.) 'Telegraph Manual,' 8vo, New York, 1859. Gavarret (J.), 'Télégraphie Électrique,' 12mo, Paris, 1861. Webb (F. C.), 'Electrical Accumulation and Conduction,' part i., crown 8vo, 1862. Blavier (E. E.), 'Traité de Télégraphie Électrique,' 2 vols. 8vo, Paris, 1867. Sabine (R.), 'The Electric Telegraph,' 8vo, 1867. Clark (Latimer), 'On Electrical Measurement,' crown 8vo, 1868. Schellen, 'Der Elektromagnetische Telegraph,' 8vo, Brunswick, 1868. Ludewig (J.), 'Der Bau von Telegraphenlinien,' 8vo, Leipzig, 1870. Clark and Sabine, 'Electrical Tables and Formulæ,' crown 8vo, 1871. Meilli (Dr. F.), 'Das Telegraphen-Recht,' 8vo, Zurich, 1871. 'British Association, Report on Electrical Standards,' edited by Professor Fleeming Jenkin, 8vo, 1873. Hoskiœr (Capt. V.), 'Guide for the Electric Testing of Telegraph Cables,' crown 8vo, 1873. Culley (R. S.), 'Handbook of Practical Telegraphy,' 8vo.

TESTING MACHINE. Fr., *Machine à éprouver*; Ger., *Prüfungs Maschine.*

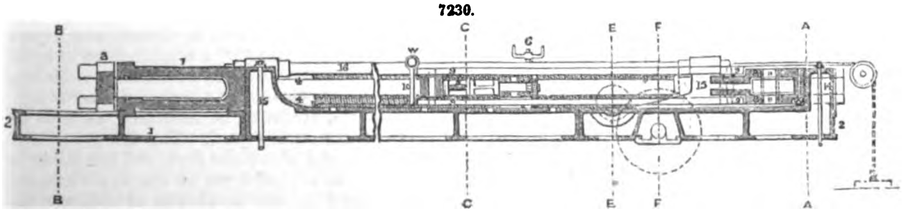
A machine for finding the amount of resistance which materials offer to applied forces under different circumstances, invented by David Kirkaldy, is shown in Figs. 7229 to 7232.

Three hydraulic cylinders in one piece, with their rams, are placed at one end of this machine, the ram being pressed outwards against a cross-head, having attached to it four powerful rods. The rams are not fixed to the cross-head, and they can be used independently of each other—either the centre one alone, or the two outer ones, or all three, according to the strain required. The rams are

7229.



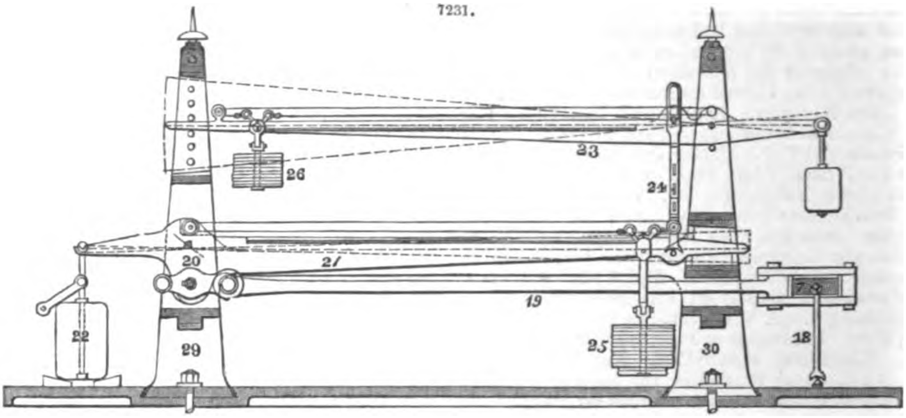
7230.



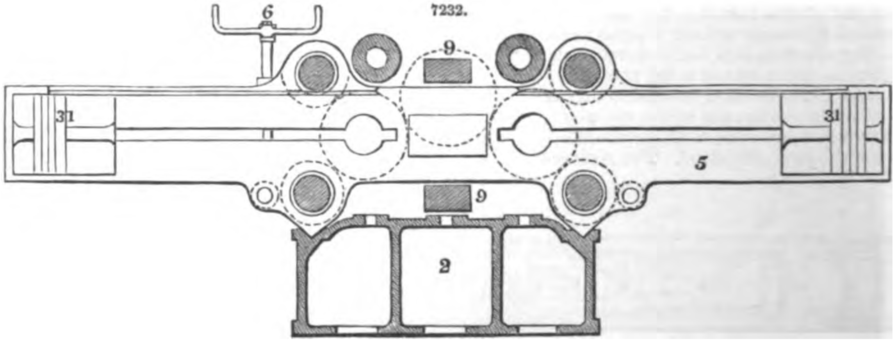
actuated by three pumps, two of which have the same area, but work with their strokes alternating, whilst the third is of larger effective area at first than either of the others, but is so contrived that by detaching a part of its plunger it may be worked afterwards with a smaller effective area. The communication of the pipe from the pumps is with the bottoms of the three cylinders, and a small screw-stop valve is applied to each cylinder. The hydraulic cylinders are fixed at one end of a long sole-plate or bed-frame, which is formed with V-grooves to guide a massive cross-head, fixed upon the four rods by screw nuts. For applying crushing strains, bending or transverse strains, and compressing, punching, or indenting strains, this cross-head is fixed on the rods so as to compress the specimen in the space between it and the cylinders; whilst for applying tensile or drawing and similar strains, the specimen is placed on the other side of the cross-head to draw the specimen towards the cylinders. The nuts, however, remain at the end of the rods, and tubular pieces of suitable lengths are put on the rods in halves between the nuts and the cross-head to transmit the strain from the nuts to the cross-head. In all applications of the apparatus the strain exerted by the rams is opposed or met by a system of levers combined with graduated steelyards, to which weights are applied whereby to measure the strain brought to bear on the specimen. The first lever works in a horizontal plane at the end of the machine opposite the rams, being supported by metal balls or by suspending links, and being acted upon by a T-piece, made in two parts, which receive

the end of the lever between them. In the case of crushing, bending, compressing, or similar strains, the T-piece is connected either by side rods or by upper and lower links to an inner cross-head,

7231.



7232.



between which and the main cross-head the specimen is placed. In the case of tensile or drawing, and of shearing strains, the specimen is connected to the T-piece outside of or beyond the main cross-head. The lever has its fulcrum knife edges bearing in a forked piece fixed to the raised end of the sole-plate or bed-frame, or it may be made with round pins bearing on anti-friction rollers. The end of the long arm of the lever is connected by a link to a short arm, projecting vertically from a horizontal graduated steelyard, working in a vertical plane and fitted with appliances for weighing or measuring the strain transmitted by means of weights. The steelyard may be formed with round journals or pins resting on anti-friction wheels, or it may have its bearing by a combination of knife edges on surfaces disposed to meet the various strains. A weight is applied to the non-indicating end of the steelyard to counterbalance the weight of the long arm, so that the minutest strains may be measured, and this weight can be easily removed when the strain to be measured exceeds its amount, so that then so much less weight will require to be put on the yard. For the purpose of measuring greater strains, a second balanced steelyard is arranged above the first, and the strain is transmitted to it from the first by a strut or rod, which can be adjusted out of the way when the upper steelyard is not to be used. The steelyards are marked in the usual way to indicate the strains, and an alarm apparatus is fitted in connection to indicate when a particular or proof strain is arrived at in performing an experiment.

Provision is made for measuring and indicating change of form in specimens operated upon, whether by elongation, compression, bending, or otherwise; and the appliance for this purpose consists of two parts connected separately to the cross-heads or other parts of the apparatus between which the specimen is placed. One part comprises a rack gearing with a pinion on a pile carried in bearings, which with a stationary pointer form the other part.

Provision is made for indicating through several turns of the dial by forming on it a spiral groove in which there works a small slide acted on by the pointer, and this slide shows in what circle or convolution of the spiral any indication is to be read. In some cases there may be a movement between the part carrying the dial and the specimen, such movement interfering with the indication of the movement, exclusively due to the specimen, and to provide for such cases the pointer ordinarily fixed with a screw may be set free to be moved by a rack acting on a pinion formed on it, such rack being connected to the specimen and correcting any movement of the part carrying the dial. The indicating appliance thus arranged may be fixed on any convenient part of the machine.

For bending specimens or subjecting them to transverse strains the main cross-head has fitted to it two blocks, which can be adjusted near to or farther from the centre; and whilst these blocks are brought to bear on two parts of the specimen, a third block pressed in the opposite direction is made

to bear on the other side of the specimen and between the two other blocks. The blocks may be arranged to grip the specimen.

For applying torsional or twisting strains, the bed-frame of the machine is provided with bearings to receive the shaft or spindle to be tested; and in testing, two toothed wheels are fixed on the spindle, upon which wheels a strain is applied in one direction by means of racks jointed to the main cross-head, whilst the opposite strain is received through a lever fixed on the shaft between the two toothed wheels. Adjustable scales to show the amount of movement are put on the wheels, the pointers to such scales being attached to the holding lever, so as to show the total movement. Wheels of different sizes may be applied and at different distances apart, and scales may be put upon suitable parts of the apparatus to measure any change in the length of the specimen. The wheels may be acted upon by chains or other jointed or flexible connections.

To measure the force actually concerned in applying bursting or collapsing strains by fluid pressure, a cylinder is fitted to the chamber or vessel into which the water or fluid used in the operation is forced, and which vessel will be the vessel or structure to be tested in the case of a bursting strain, but will contain the vessel or structure to be tested in the case of a collapsing strain. The cylinder is fitted with a piston, and the chamber or vessel is placed in the machine in such a way that the rod of the piston may communicate the pressure on its area through the T-piece and lever to the steelyards. If the pressure of the atmosphere is to be used in collapsing the specimen or vessel, the cylinder and piston is arranged in the machine in such a way that the piston will be drawn outwards relatively to the vessel by the action of the hydraulic rams, and so tend to produce a vacuum inside the vessel, water or other liquid being contained therein.

The machine may also be used for measuring and indicating change of form or strength in a specimen when subjected to heat or cold, as the apparatus for applying the heat or cold may be easily introduced into the machine in such a way that the specimen under experiment may act on or be acted on by one or both cross-heads.

It is an important feature of the improved apparatus that the specimens operated upon are placed in a horizontal position, which has many practical advantages, and amongst other things it admits of the application of combinations of strains. Thus percussive, vibratory, jarring, and other strains, may be applied to the specimens whilst subjected to any desired degree of tensile, transverse, compressive, or similar strains.

When the apparatus is not required to apply great strains, one or two hydraulic cylinders or a screw or combination of screws may be substituted for the three hydraulic cylinders.

Fig. 7229 is a plan of the machine, with the strain-indicating apparatus in horizontal section; Fig. 7230 is a longitudinal vertical section of the main part of the machine; Fig. 7231 is a side elevation of the strain-indicating apparatus, with the framing in vertical section; and Fig. 7232 is a transverse vertical section taken at the lines C, C, Figs. 7229, 7230. The different parts represented in the figures are referred to by the numerals 1, 2, 3, and so on. The hydraulic cylinder 1 is fixed at one end of a long sole-plate or bed-frame 2, which, for convenience, is cast in four separate parts, and rigidly bolted to each other, and held down by tie-bolts to a massive foundation of masonry. The bed-frame is formed with V-grooves along the sides to guide the cylinder cross-head 3, which has attached to it the four rods 4, and to guide a second cross-head 5, which is fixed by screw nuts on the rods 4, these being screwed for the purpose. For applying crushing strains, bending or transverse strains, and compressing, punching, or indenting strains, this cross-head 5 is fixed on the rods 4 in such a position as to compress the specimen S in the space between it and the cylinder 1; whilst for applying tensile or drawing and similar strains, the specimen is placed on the other side of the cross-head 5 to draw the specimen towards the cylinder 1.

In Fig. 7229 the machine is shown as applying a bending strain to a specimen S. The rods 4 are represented as screwed for a considerable portion of their length, in order that the cross-head 5 may be adjusted upon them in any convenient position; and to facilitate such adjustment provision is made for working the four screw nuts simultaneously, they being formed with pinion-teeth connected by intermediate toothed wheels, and worked by a hand-shaft 6 through a pair of bevel-pinions. The working of the nuts backwards and forwards may be avoided by applying tubular pieces of suitable lengths to be put on the rods in halves between the nuts and the cross-head, in which case the nuts might always remain at the ends of the rods, the tubular pieces transmitting the strain to them from the cross-head when this is placed nearer to the cylinder. In all applications of the apparatus the strain exerted by the cylinder 1 is opposed or met by a system of levers combined with graduated steelyards, to which weights are applied to measure the strain brought to bear on the specimen. The first lever 7 works in a horizontal plane at the end of the machine opposite to the cylinder 1, being supported on metal balls or struts or by suspending links, and being acted upon by a T-piece 8 made in two parts, which receive the lever 7 between them. In the case of crushing, bending, compressing, or similar strains, the T-piece 8 is connected either by side rods or by upper and lower links 9, as shown in Figs. 7229, 7230, to an inner cross-head or block 10, between which and the main cross-head 5 the specimen S is placed. In the case of tensile or drawing, and of shearing and other similar strains, the specimen is connected to the T-piece 8 outside of or beyond the main cross-head 5. The strain of the T-piece is communicated to a vertical pin 11 fixed in the lever 7, and fitted with steel knife edges, which bear against steel pieces fitted in eyes which are formed in the upper and lower parts of the T-piece to receive the pin 11. The fulcrum knife edges of the lever 7 are fitted upon a similar pin 12 fixed in the lever, and they bear upon steel pieces fitted in eyes formed in a forked piece 13 fixed to the raised end 14 of the bed-frame 2. The strain acting between the end of the bed-frame and the abutment 15, against which the inner end of the cylinder 1 bears, is met by two cast-iron rods 16, as well as by the bottom of the bed-frame itself. These rods 16 are keyed at one end in the abutment 15, and at the other end in an abutment 15 formed on the bed-frame, and connected by side bars to the raised end or abutment 14. The first lever 7 is represented as supported by struts 18, at each end, the lever being fitted with knife edges to bear on the struts, and the struts bearing on knife edges on the bed-frames; and this

arrangement admits of the very slight movements of the lever with the least friction. The end of the long arm of the lever 7 is connected by a link 19 to a short arm 20 projecting vertically downwards from a horizontal graduated steelyard 21 working in a vertical plane, and fitted with appliances for weighing or measuring by means of weights the strain transmitted. The link 19 is connected to the first lever 7 by means of upper and lower plates connected together, and to the lever by pins, and formed with eyes, into which a pin in the lever is entered, and on steel pieces in which knife edges on the pin bear. The link is connected to the steelyard 21 in a similar way.

The steelyard 21 may be formed with round journals or pins resting on anti-friction wheels, but a combination of knife edges bearing on surfaces disposed to meet the various strains is preferable. A weight 22 is applied to the non-indicating end of the steelyard 21 to counterbalance the weight of the long arm, so that the minutest strains may be measured, and this weight can be easily removed when the strain to be measured exceeds its amount, so that then as much less weight will require to be put upon the yard. For the purpose of measuring greater strains a second balanced steelyard 23 is arranged above the first, and the strain is transmitted to it from the first by a strut or rod 24, which can be adjusted so as to be inactive when the upper steelyard is not to be used. The strut 24 is forked at both ends, and the strain is communicated by knife edges on the lower yard, and is received by knife edges on the upper one. The strut is in two pieces, which are keyed together, and when it is to be inactive the parts are keyed together in such a way as to shorten it, whilst the upper parts being looped round the upper knife edges, it is prevented from falling. The steelyards 21, 23, are marked in the usual way, and are provided with weights 25, 26, to indicate the strains, and a bell alarm apparatus is fitted in connection with each yard to indicate when a particular or proof strain is arrived at in performing an experiment. The weights are easily moved along the yards by means of endless cords passed round pulleys at each end, actuated by small hand-wheels. The yards are carried by two standards, 29, 30, each of which is formed in two pieces, so as to enclose the yards between them, and with openings for the points of the yards to work in, these openings being fitted with wooden striking pieces for the yards to come in contact with when any sudden movement takes place from a specimen giving way. With a similar object, wooden striking pieces are also fitted in the eyes of the T-piece 8, and on the raised abutment 14, where the T-piece would strike. Provision is further made for measuring and indicating change of form in the specimens operated upon, whether by elongation, compression, bending, or otherwise; and the appliance for this purpose consists of two parts to be connected separately to the cross-heads or other parts of the machine between which the specimen may be placed. See MATERIALS OF CONSTRUCTION, *Strength of.*

TIN. FR., *Étain;* GER., *Zinn;* ITAL., *Stagno;* SPAN., *Estaño.*

Tin, Sn. Atomic weight = 118. Molecular weight unknown.

Tin is found in nature as an oxide, sometimes mixed with sulphur. This sulphuret of tin, or tin pyrites, is found chiefly in the Cornish mines, but it is of little value commercially. Only a few localities produce this metal, though it is one of the earliest known. Cornwall has always been the main source of supply to the whole world, but recently extensive tin-producing districts have been discovered in Australia, and it is probable that these deposits, which have been proved to be very rich, will furnish large quantities of the metal in the future. Malacca, in the Malayan Peninsula, and some of the neighbouring islands, have long produced tin in small quantities, and the tin there found is in a nearly pure state. There is but one ore of tin of any importance, namely, the peroxide, which, in its pure state, consists of tin 78 and oxygen 22 per cent. The ore is of various colours, as grey, several shades of yellow, red, and black. Its specific gravity, which is a noteworthy feature, is 6·9. Tin ore occurs in mineral veins running through granite or slate rocks, or disseminated in crystals through their mass. The tin stone which is obtained from the veins or lodes, as they are called in Cornwall, is known as mine tin; while that procured by washing alluvial deposits is called stream tin. The latter is the result of the disintegration of granite and other rocks containing veins of tin. The ore is first roasted in contact with the air, in order to convert the whole of it into oxide; it is then heated in contact with carbon, the process converting the carbon into oxide of carbon, and the latter reducing the oxide of tin to the state of metallic tin.

$$\underset{\text{Oxide of tin.}}{Sn\,\Theta_2} + \underset{\text{Oxide of carbon.}}{2\,\text{C}\Theta} = \underset{\text{Carbonic anhydride.}}{2\,\text{C}\Theta_2} + \underset{\text{Tin.}}{Sn}$$

Tin is a silvery white metal with a high metallic lustre. It possesses a crystalline texture, which may be made apparent by attacking its surface with an acid. The crystals are of the pyramidal or tetragonal system. It is in consequence of its crystalline texture that a bar of tin, when bent, emits a peculiar creaking sound known as the *cry* of tin. Tin is a soft metal, and very malleable; it may be beaten out into very thin laminæ, in which form it is known as *tinfoil.* Tin is susceptible of being pulverized directly, but it is usually obtained in a pulverized state by fusing it and keeping it violently agitated while solidifying. It fuses at a temperature of 442°. At ordinary temperatures it is not acted upon by exposure to the air; but it becomes rapidly oxidized when in a state of fusion, and at a red heat it burns with a brilliant white flame, producing stannic anhydride, $Sn\,\Theta_2$. The acids, such as nitric acid or nitrate of potassa, act violently upon tin, and produce either metastannic acid $Sn_5\,H_{10}\,\Theta_{15}$, or stannate of potassa $Sn\,K_2\,\Theta_3$. Tin unites directly with phosphorus, sulphur, chlorine, bromine, and iodine. Hydrochloric acid dissolves it, with extrication of hydrogen, and forms protochloride of tin.

$$\underset{\text{Hydrochloric acid.}}{2\left(\begin{matrix}H\\Cl\end{matrix}\right\}\Big)} + \underset{\text{Tin.}}{Sn} = \underset{\text{Protochloride of tin.}}{\left.\begin{matrix}Sn\\Cl\end{matrix}\right\}} + \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}}$$

Unlike all the metalloids we have noticed, tin forms with oxygen an oxide $Sn\,\Theta$, that is a true basic anhydride, capable of combining directly with the acid anhydrides and the acids, with

extrication of water, and forming salts. These salts are distinguished by the following characteristics;—

1. Water decomposes them and forms an insoluble sub-salt, whilst a certain quantity of acid which has been liberated holds in solution another part of the salt not decomposed.

2. Potassa determines in them the formation of a precipitate which is soluble in an excess of the reagent, but which is again thrown down when the solution is exposed in a vacuum.

3. Chloride of gold produces in the solution of these salts a purple precipitate known as purple of Cassius.

4. With hydrosulphuric acid they give a brown precipitate soluble in hydrosulphate of ammonia, and boiling hydrochloric acid, but insoluble in ammonia.

The combinations of tin with the metalloids which we have previously considered are the following;—

Protochloride of Tin, $Sn\,Cl_2$.—The protochloride of tin may be obtained by dissolving the metal in hydrochloric acid; it is a solid crystallized substance, and it becomes volatile at a dull red heat. Water decomposes it into hydrochloric acid and oxychloride of tin, $Sn_2\,Cl_2\,\Theta$.

$$\underset{\text{Protochloride of tin.}}{2\left(\begin{matrix}Sn''\\Cl_2\end{matrix}\Big\}\right)} + \underset{\text{Water.}}{\left(\begin{matrix}H\\H\end{matrix}\Big\}\right)\Theta} = \underset{\text{Oxychloride of tin.}}{Sn_2\,Cl_2\,\Theta} + \underset{\text{Hydrochloric acid.}}{2\left(\begin{matrix}H\\Cl\end{matrix}\Big\}\right)}$$

The solution of bichloride of tin, when heated with hydrochloric acid and sulphurous anhydride, gives a yellow deposit of bisulphide of tin.

$$\underset{\text{Protochloride of tin.}}{6\left(\begin{matrix}Sn\\Cl_2\end{matrix}\Big\}\right)} + \underset{\text{Sulphurous anhydride.}}{2\,S\,\Theta_2} + \underset{\text{Hydrochloric acid.}}{8\left(\begin{matrix}H\\Cl\end{matrix}\Big\}\right)} = \underset{\text{Bisulphide of tin.}}{Sn\,S_2} + \underset{\text{Bichloride of tin.}}{5\left(\begin{matrix}Sn\\Cl_4\end{matrix}\Big\}\right)} + \underset{\text{Water.}}{4\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right)}$$

Protochloride of tin has a strong affinity for chlorine, which converts it into perchloride of tin, and for oxygen, which converts it into a compound of perchloride of tin and stannic acid.

$$\underset{\text{Bichloride of tin.}}{2\,Sn\,Cl_2} + \underset{\text{Oxygen.}}{\begin{matrix}\Theta\\\Theta\end{matrix}\Big\}} + \underset{\text{Water.}}{\begin{matrix}H\\H\end{matrix}\Big\}\Theta} = \underset{\text{Stannic acid.}}{\begin{matrix}(Sn\,\Theta)''\\H_2\end{matrix}\Big\}\Theta_2} + \underset{\text{Perchloride of tin.}}{Sn\,Cl_4}$$

Perchloride of Tin.—Perchloride of tin is prepared by passing a stream of chlorine in excess over tin slightly heated. It is a smoking liquid, which gives with water a crystallizable hydrate, $Sn\,Cl_4$, 5 aq. The bases decompose it into stannate and metallic chloride.

$$\underset{\text{Perchloride of tin.}}{\begin{matrix}Sn\\Cl_4\end{matrix}\Big\}} + \underset{\text{Potassa.}}{6\left(\begin{matrix}K\\H\end{matrix}\Big\}\Theta\right)} = \underset{\text{Stannate of potassa.}}{\begin{matrix}(Sn\,\Theta)\\K_2\end{matrix}\Big\}\Theta_2} + \underset{\text{Chloride of potassium.}}{4\left(\begin{matrix}K\\Cl\end{matrix}\Big\}\right)} + \underset{\text{Water.}}{3\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right)}$$

Hydrosulphuric acid gives with the perchloride a yellow precipitate of sulphide of tin, soluble in ammonia, hydrosulphate of ammonia and boiling hydrochloric acid. Chloride of gold does not precipitate it.

Of the bromides and iodides of tin, little need be said. The protobromide is prepared in the same way as the protochloride, and it possesses similar qualities. The same may be said of the perbromide. The proto-iodide of tin is prepared by the direct combination of one atom of tin and two atoms of iodine. Its properties are similar to those of the protochloride and the protobromide. The periodide is also obtained by direct synthesis, and it possesses qualities similar to those of the perchloride and the perbromide.

Fluorides of Tin.—Two fluorides of tin are known, a protofluoride $Sn\,Fl_2$, and a bifluoride $Sn\,Fl_4$. They are obtained by treating the protoxide and the stannic anhydride by hydrofluoric acid.

$$\underset{\text{Protoxide of tin.}}{Sn\,\Theta} + \underset{\text{Hydrofluoric acid.}}{2\left(\begin{matrix}H\\Fl\end{matrix}\Big\}\right)} = \underset{\text{Protofluoride of tin.}}{Sn\,Fl_2} + \underset{\text{Water.}}{\begin{matrix}H\\H\end{matrix}\Big\}\Theta}$$

$$\underset{\text{Stannic anhydride.}}{Sn\,\Theta_2} + \underset{\text{Hydrofluoric acid.}}{4\left(\begin{matrix}H\\Fl\end{matrix}\Big\}\right)} = \underset{\text{Perfluoride of tin.}}{Sn\,Fl_4} + \underset{\text{Water.}}{2\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right)}$$

Protoxide of Tin.—When protochloride of tin is precipitated by potassa, a minimum hydrate of tin, $\begin{matrix}Sn\\H_2\end{matrix}\Big\}\Theta_2$, is obtained, which is of a white colour and insoluble in water. It is capable of acting both as a base and as an acid, that is, it will produce the double decomposition both with the bases and the acids.

$$\underset{\text{Minimum hydrate of tin.}}{\begin{matrix}Sn\\H_2\end{matrix}\Big\}\Theta_2} + \underset{\text{Sulphuric acid.}}{\begin{matrix}S\,\Theta_2\\H_2\end{matrix}\Big\}\Theta_2} = \underset{\text{Sulphate of tin.}}{\begin{matrix}S\,\Theta_2\\Sn\end{matrix}\Big\}\Theta_2} + \underset{\text{Water.}}{2\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right)}$$

$$\underset{\text{Minimum hydrate of tin.}}{\begin{matrix}Sn\\H_2\end{matrix}\Big\}\Theta_2} + \underset{\text{Potassa.}}{2\left(\begin{matrix}K\\H\end{matrix}\Big\}\Theta\right)} = \underset{\text{Stannite of potassa.}}{\begin{matrix}Sn\\K_2\end{matrix}\Big\}\Theta_2} + \underset{\text{Water.}}{2\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right)}$$

When the watery solution of stannite of potassa is left in a vacuum, it deposits black crystals of anhydrous oxide of tin, which decrepitate when heated and are changed into small flakes of an olive

colour. The same solution, when subjected to the action of heat, is converted into stannate of potassa and tin which is thrown down.

$$2\left(\begin{matrix}Sn\\K_2\end{matrix}\right\}\Theta_2\Big) + \begin{matrix}H\\H\end{matrix}\Big\}\Theta = \begin{matrix}(Sn\,\Theta)\\K_2\end{matrix}\Big\}\Theta_2 + 2\left(\begin{matrix}K\\H\end{matrix}\Big\}\Theta\right) + Sn$$

Stannite of potassa. Water. Stannate of potassa. Potassa. Tin.

The minimum hydrate of tin when boiled in an excess of ammonia loses water, leaving anhydrous protoxide of tin of an olive colour.

$$\begin{matrix}Sn\\H_2\end{matrix}\Big\}\Theta_2 = Sn\,\Theta + \begin{matrix}H\\H\end{matrix}\Big\}\Theta$$

Hydrate of tin. Anhydrous protoxide of tin. Water.

If the protochloride of tin is precipitated by an excess of ammonia, boiled for a moment and the mass dried without separating the hydrochlorate of ammonia formed, protoxide of tin is obtained of a bright red colour. This oxide assumes an olive hue when rubbed with a hard substance. Thus the protoxide of tin is polymorphous, and the most stable of the three forms it may affect is that which presents an olive colour.

Stannic Anhydride, $Sn\,\Theta_2$.—Stannic anhydride is produced by calcining the stannic and metastannic acids. It constitutes a white mass insoluble in water and capable of giving stannates when heated with an excess of potassa or soda.

Stannic Acid, $\begin{matrix}(Sn\,\Theta)\\H_2\end{matrix}\Big\}\Theta_2$.—This acid is nothing but the first anhydride of the unknown acid $\begin{matrix}Sn\\H_4\end{matrix}\Big\}\Theta_4$. It is obtained by precipitating the stannates by hydrochloric acid.

$$\begin{matrix}(Sn\,\Theta)\\K_2\end{matrix}\Big\}\Theta_2 + 2\left(\begin{matrix}H\\Cl\end{matrix}\right\}\Big) = \begin{matrix}(Sn\,\Theta)\\H_2\end{matrix}\Big\}\Theta_2 + 2\left(\begin{matrix}K\\Cl\end{matrix}\right\}\Big)$$

Stannate of potassa. Hydrochloric acid. Stannic acid. Chloride of potassium.

Stannic acid is a white gelatinous substance, soluble in dilute nitric and sulphuric acid. Under the influence of a gentle heat it is converted into metastannic acid.

$$5\left(\begin{matrix}(Sn\,\Theta)\\H_2\end{matrix}\Big\}\Theta_2\right) = \begin{matrix}(Sn\,\Theta)_5\\H_{10}\end{matrix}\Big\}\Theta_{10}$$

At a red heat it loses its water, and is converted into stannic anhydride. It combines with the bases giving salts the formula of which is $\begin{matrix}(Sn\,\Theta)\\M\,H\end{matrix}\Big\}\Theta_2$.

Metastannic Acid, $\begin{matrix}(Sn\,\Theta)_5\\H_{10}\end{matrix}\Big\}\Theta_{10}$.—This is the first anhydride of the unknown pentastannic acid, $\begin{matrix}Sn_5\\H_{12}\end{matrix}\Big\}\Theta_{16}$. It is obtained by heating tin with nitric acid.

$$15\,Sn + 5\left(\begin{matrix}H\\H\end{matrix}\Big\}\Theta\right) + 20\left(\begin{matrix}N\,\Theta_2\\H\end{matrix}\Big\}\Theta\right) = 3\left(\begin{matrix}(Sn\,\Theta)_5\\H_{10}\end{matrix}\Big\}\Theta_{10}\right) + 20\,N\,\Theta$$

Tin. Water. Nitric acid. Metastannic acid. Binoxide of nitrogen.

Metastannic acid is a white, crystalline substance, insoluble in water and in dilute nitric and sulphuric acids; it dissolves, however, in hydrochloric acid, and in concentrated sulphuric acid. Water does not throw it down from these solutions.

Metastannic acid is insoluble in ammonia when it has been prepared by means of nitric acid. But if it is thrown down from the solution of one of its salts by means of an acid, it dissolves readily in that alkali. With the bases it forms salts, the formula of which is $\begin{matrix}(Sn\Theta)_5\\H_8\\M_2\end{matrix}\Big\}\Theta_{10}$. When heated with an excess of the base, these salts are converted into stannates.

Sulphides of Tin.—There are two sulphides of tin, a protosulphide Sn S, and a bisulphide $Sn\,S_2$. Both of these may be obtained by passing sulphuretted hydrogen through the corresponding chlorides.

$$\begin{matrix}Sn\\Cl_4\end{matrix}\Big\} + 2\left(\begin{matrix}H\\H\end{matrix}\Big\}S\right) = Sn\,S_2 + 4\left(\begin{matrix}H\\Cl\end{matrix}\right\}\Big)$$

Perchloride of tin. Sulphuretted hydrogen. Bisulphide of tin. Hydrochloric acid.

$$\begin{matrix}Sn\\Cl_2\end{matrix}\Big\} + \begin{matrix}H\\H\end{matrix}\Big\}S = Sn\,S + 2\left(\begin{matrix}H\\Cl\end{matrix}\right\}\Big)$$

Protochloride of tin. Sulphuretted hydrogen. Bisulphide of tin. Hydrochloric acid.

Another method of preparing the bisulphide of tin is to heat together 12 parts of tin amalgamated with 6 parts of mercury, 7 parts of sulphur, and 6 parts of chloride of ammonium, until the mercury and the chloride of ammonium are completely evaporated. When prepared in this way, the bisulphide of tin is known as mosaic gold. Both sulphides of tin unite with the alkaline sulphides, producing sulphosalts. See ORES, *Machinery and Processes employed to Dress.*

TUNNELLING. FR., *Percement des tunnels;* GER., *Tunnelbau;* ITAL., *Perforazione delle gallerie;* SPAN., *Construccion de túneles.*

See RAILWAY ENGINEERING.

TURBINE WATER-WHEEL. FR., *Turbine;* GER., *Turbine;* ITAL., *Turbine;* SPAN., *Turbina.*

A turbine is a water-wheel, having generally a vertical axis, to which motion is imparted by a column of water entering at the centre and passing off at the circumference, as in that originally

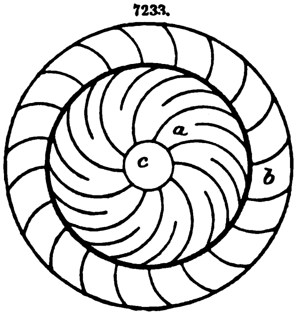
invented by Fourneyron; or the reverse, as in Thomson's vortex wheel. In another arrangement, that of Burdin, the water enters from above the wheel and passes off beneath; in this system therefore the distance of the water from the axis remains constant. In some cases, as for example, Jonval's turbine and Gerard's screw wheel, the axis is horizontal.

Turbines are usually divided into high and low pressure, the former being driven by a small body of water having a high fall, and are therefore particularly suitable for erection in hilly districts, where the supply of water is small and variable, while at the same time there exist great facilities for the easy construction of reservoirs; the latter are adapted to a large body of water having a low fall, in some cases not more than 9 inches.

The oldest forms of wheels having a vertical axis are found in the south of France and in Algeria. The most simple of these, called *rouets volants*, consist merely of an upright shaft on which is fixed the wheel, having plain curved floats, driven by the impact of a column of water discharged on the upper surface from a wooden trough or spout. The maximum effect obtained from these wheels, under the most favourable circumstances, is ·35 of the absolute work due to the fall. Another form found in these parts, called *roues à cuve*, consists of a wheel having curved or spoon-shaped buckets, erected in a casing of wood or masonry; the water being applied by a pipe at one point on the circumference, and making its exit at the centre of the wheel from the bottom of the case or tub.

It was from an examination of this wheel that Fourneyron was led to make those experiments which resulted in the invention of the modern turbine, the first being erected by him in Franche-Comté in the year 1827. These turbines, as well as several others, have already been illustrated and described under the head of Hydraulic Machines; we shall therefore confine ourselves to an examination of the principles which govern the action of these wheels, and of the proper proportions which should exist among their several parts in order to obtain the maximum effect from any given fall. Numerous experiments made by Morin to determine the duty of turbines and the proportions of their several parts which give a maximum duty, have thrown considerable light upon these difficult problems. In some of the following remarks we shall avail ourselves of the experience of this celebrated hydraulic engineer.

7233.



Turbines which receive the Water at the centre and discharge from the circumference.—From Fig. 7233 it will be seen that this wheel is composed of two separate and opposed series of radiating buckets; those in the interior *a* being fixed and serving to direct the water, conveyed to them from the fall by the pipe *c*, with a tangential motion upon the face of the buckets *b* which constitute the wheel proper, and to which motion is thus imparted.

Percentage of Work.—From a number of experiments which have been made with this class of wheel, it has been found that if we make n the number of revolutions made by the wheel in one minute, V the velocity due to the total fall, R the exterior radius of the wheel, the number n being comprised within the limits of the equation $n = \frac{3 \cdot 3\ V}{R}$ and $n = \frac{5 \cdot 6\ V}{R}$, when the opening of the directing vanes or sluices exceeds $\frac{2}{3}$ the height of the buckets, the useful effect transmitted by the wheel will be represented, to within $\frac{1}{15}$, by the formula $P\,v = 40 \cdot 5\ Q\,H$ to $P\,v = 43 \cdot 7\ Q\,H$ foot pounds. Where P equals the mean force transmitted to the outer circumference of the wheel in pounds; V the velocity of the outer circumference of the wheel in feet a minute; Q the quantity of water in cubic feet passing in one minute, and H the total fall in feet.

When the opening is from $\frac{1}{3}$ to $\frac{2}{3}$ the height of the buckets, the useful effect will not be more than $P\,v = 37 \cdot 4\ Q\,H$ to $P\,v = 41 \cdot 0\ Q\,H$ foot pounds; and for smaller openings it will decrease still faster.

To exemplify the use of the formula, let it be required to find the useful effect transmitted by one of Fourneyron's turbines under the following conditions. Quantity of water passing in one minute 1680 cub. ft. = Q; total fall 22 ft. = H; the absolute work of the motor is

$$1680 \times 22 \times 62 \cdot 4 = 2303347 \text{ foot pounds;}$$

and the number of revolutions being kept between the indicated limits, we shall have

$$40 \cdot 5 \times 36960 = 1496880 \text{ to } 43 \cdot 7 \times 36960 = 1611152 \text{ foot pounds}$$

for the amount of useful effect.

Proportions of Parts.—In calculating the proportions which should exist between the various parts of a wheel of this description we shall have, R the interior radius of the sluice cylinder, R′ the exterior radius of the turbine, R″ the interior radius of the turbine, and seeing that the mean useful effect is equal to ·65 of the absolute work of the motor, we shall have the relation $P\,v = 40 \cdot 5\ Q\,H$, and $Q = \frac{P\,v}{40 \cdot 5\ H}$, from which we shall be able to determine the volume of water Q passing in one minute necessary with a given fall H to obtain the required useful effect $P\,v$. If the volume of water Q is known, the above formula will give the useful effect.

In order to obtain the maximum effect, the bottom of the wheel should be placed a few inches above the mean level of the standing tail-water.

The mean velocity of the water in the sluice should not exceed 5 ft. a second; and the radius of this cylinder is calculated by the formula $R = \sqrt{\frac{Q}{4 \cdot 712}}$. Adding to the result thus obtained 1·2 in. in order to allow for the thickness of the metal and a slight amount of play or clearance

between the two cylinders, we shall have the interior radius of the wheel $R'' = R + 1 \cdot 2$ in.; and the exterior radius will be $R' = 1 \cdot 33\ R''$.

Dimensions and Number of the Directing Vanes or Guides, and of the Buckets.—When the quantity of water passing through the wheel in one minute is between 13,000 and 20,000 gallons, the thickness a of the sheet of water passing between two consecutive vanes, or the shortest distance of the latter apart, should not exceed $2 \cdot 4$ in. And in proportion as the quantity of water decreases, this distance should also be reduced. The distance between two consecutive vanes measured on the circumference R will be $l = 2a +$ from $\cdot 16$ to $\cdot 20$ in., according to the thickness of the iron plate of which they are made. Dividing the circumference of the sluice cylinder $6 \cdot 28$ R by l and taking the nearest whole number of the quotient which is divisible by several factors, for the number n of the directing vanes or guides, the number n' of the buckets will be $n' = 1 \cdot 33\ n$. The interior height e of the turbine and the opening of the sluice will be $e = \dfrac{3 \cdot 14\ R^2}{n\,a}$. If, however, the quantity of water sometimes falls considerably below and at other times rises considerably above the average, it is better to increase the height e, and to divide the turbine by diaphragms of thin plate iron, into two or more horizontal sections.

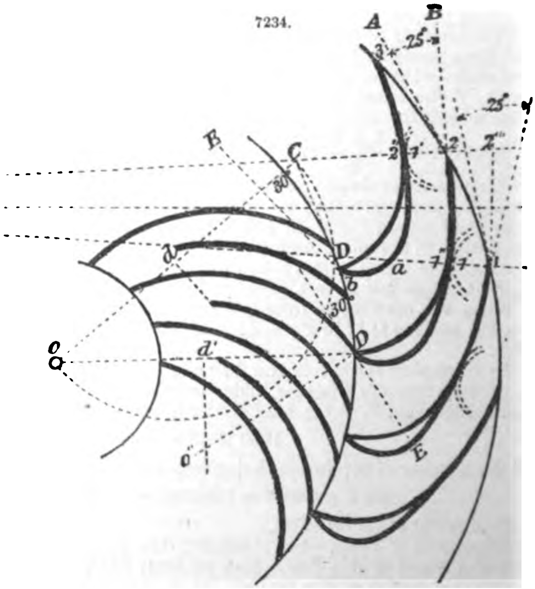
The mean velocity of the exterior circumference of the turbine will be $V = \cdot 55 \sqrt{2gH}$ to $\cdot 60 \sqrt{2gH}$.

Observations.—The preceding formulæ are only applicable to falls of 6 ft. 6 in. and under. For higher falls, or where the velocity of the stream is great, the size of the wheel should be increased by making $R' = 1 \cdot 4\ R''$ for falls ranging from $6 \cdot 6$ to $16 \cdot 4$ ft.; and for still higher falls $R' = 1 \cdot 5\ R''$.

The distance between the buckets on the interior and exterior circumferences of the wheel will be found by the formulæ $\dfrac{6 \cdot 28\ R'}{n'}$ and $\dfrac{6 \cdot 28\ R''}{n'}$; and deducting the thickness of the metal employed, we shall have the distance l and l' from one bucket to the next, measured on these circumferences. The shortest distance a' from one bucket to the next, including the thickness of the metal, will be approximatively determined by the formula $a' = \dfrac{6 \cdot 28\ R''}{2\,n'}$. And deducting the thickness of the metal we shall have that assumed by the sheet of water when escaping from the wheel.

Mode of delineating the Buckets.—The number n of the buckets of the turbine being determined, as well as their shortest distance a' at the exterior circumference, divide this circumference into the number n of equal parts, as 1 2, 2 3, and so on, Fig. 7234. From each of these points draw tangents as 2 A, and lines as 2 B inclined at 25° to the tangents. From the points 1, 2, as centres, with radius 1 1′, 2 2′, equal to the shortest interior distance a of the buckets, describe arcs of circles; increase this radius by the thickness of the metal forming the buckets, and describe other arcs, as 1 1″, 2 2″; then the interior curve of the buckets will be tangential to these arcs, and the exterior curve tangential to the arcs 1 1′, 2 2′. The exterior surface of the bucket may then be determined in the following manner. Produce the line 2 2‴ outside the exterior circumference and make 2 2‴ equal 2 2′; join the points 1 and 2‴. At the centre of the line 1 2‴ erect a perpendicular, and the point where this perpendicular cuts the line 2 2′ produced will be the centre of the arc of the circle forming between the points 2 and 1′ the profile of the bucket. For the portion of this profile comprised between the point 1′ and the interior circumference we proceed in the following manner. From the point C, with radius C 2″, describe an arc cutting the inner circumference in D, which will complete the trace of the bucket. The position of the point C is determined in the following manner. From the centre of the wheel O draw a line, as O C, cutting the line 2 2′ prolonged in a point C situate outside the interior circumference, bisect the line in d, and from d, with radius d O, describe a semicircle which will cut the interior circumference of the wheel as at D; then, if the distance D C equals C 2″, C is the point required. If the distance D C is less than C 2″ draw the line O C nearer to 2″, if it is greater draw it farther from 2″. After two or three trials the position of the point C may be found with sufficient accuracy for all practical purposes. In order to narrow the discharging channels a little at their commencement, it is necessary to increase the thickness of the bucket on its exterior surface. The form of curve 2′ a b which should be adopted may be traced with sufficient accuracy by hand, taking care, however, that it starts tangentially from the first part at 2′ and gradually rejoins the interior surface of the bucket at D.

7234.



To trace the Directing Vanes.—From the point D draw a line D E making with the tangent D F on the interior circumference an angle of 30°; this will give the direction which should be taken by the water when leaving the supply cylinder. At the point D on the line D E erect a perpendicular D O″; from the centre d' of the line D O erect a perpendicular d' O″; and the point O″ where these perpendiculars intersect will be the point from which to describe with radius O″ D the profile of the directing vane. The half only of these directing vanes will be extended to the central supply cylinder; the length of the remainder being determined by a circle drawn from the centre O with radius O O″.

Example.—Let it be required to construct a turbine of 40 horse-power for a fall of 6 ft., which shall return a useful effect of ·65 of the total work. Then we shall have $Q = \frac{33000 \times 40}{40 \cdot 5 \times 6} = 5432$ foot pounds.

The radius of the sluice cylinder will be $R = \sqrt{\frac{5432}{4 \cdot 712}} = 33 \cdot 5$ in., and adding to this 1·2 in. for the thickness of metal and clearance, we shall have $R'' = 34 \cdot 7$ in., and $R' = 1 \cdot 33 \times 34 \cdot 7 = 49 \cdot 7$ in.

Taking $a = 2 \cdot 4$ in. and deducing from it the distance apart of the buckets on the interior circumference of the wheel $l = 2\,a = 4 \cdot 8$ in.; then $n = \frac{6 \cdot 28\,R''}{l} = 43 \cdot 31$, and taking the round number $n = 44$ for the number of directing vanes, we shall have $n' = 58$ for the number of buckets. The distance apart of the vanes will be $\frac{6 \cdot 28 \times 34 \cdot 7}{44} = 4 \cdot 93$ in., and the thickness of the metal being taken as ·2 in., we shall have $a = 2 \cdot 66$ in. The arc occupied by each bucket will be $\frac{6 \cdot 28 \times 49 \cdot 7}{58} = 5 \cdot 4$ in.; and the thickness of the sheet of water passing between two consecutive buckets will be $a' = 2 \cdot 7$ in.

The velocity of the exterior circumference of the wheel in feet a second will be $V'' = \cdot 55 \sqrt{64 \cdot 4 \times 6} = 10 \cdot 8$, and the number of revolutions made by the turbine in one minute will be $N = \frac{10 \cdot 8 \times 60}{6 \cdot 28 \times 2 \cdot 9} = 30 \cdot 6$.

Wheels of this kind may be erected with advantage under any fall whether high or low; they occupy but little space, and their weight in comparison with the power which they exert is very small. They exert a useful effect equal to ·65 and often to ·70 of the absolute work of the fall, when the sluice-gates are open nearly or quite to the full height of the wheel. They may be driven at varying velocities without any notable variation in the maximum effect. They will work at a great depth under water without the proportion of useful effect to the absolute work being sensibly diminished; so that by placing them at the lowest level of the water, we may at all times utilize the full height of the fall.

This wheel possesses the following defect. When the opening of the sluice-gates is less than two-thirds the height of the wheel, the useful effect will be found to decrease in proportion as the openings become smaller. This constitutes a serious defect in those situations where the supply of water is very variable. In fact, in the time of floods the wheel with its sluice-gates open to their full extent will, although drowned, return a useful effect of ·70 of the total work of the fall; whilst in seasons of drought when the supply of water is small, and the height of the fall at its maximum, as the sluices can be opened but a fraction of the height of the wheel, the useful effect will fall to ·60 and often to ·50 of the total work. This defect may however, to a great extent, be remedied by the employment of horizontal diaphragms, dividing the wheel into several horizontal zones.

A regulator may be used with this turbine, but in that case the sluices cannot be opened to their full extent.

Turbines which receive the Water at the circumference and discharge from the centre.—The action and construction of this class of wheel has been fully described under the head of Hydraulic Machines, pages 1923 and 1932.

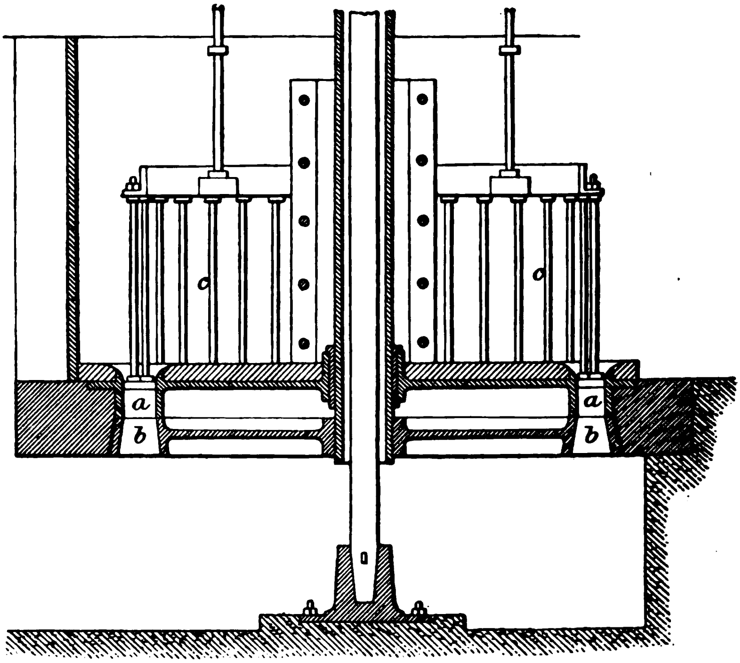
Turbine which receives the Water from above and discharges from the lower side.—This turbine is composed of two cast-iron zones or rings placed one above the other, Fig. 7235, the lower one, which is the wheel proper, containing the buckets b, which are constructed with helicoidal curved surfaces; in the upper zone, which is fixed, are placed the directing vanes or guides a, which serve to discharge the water at the proper angle on the face of the buckets beneath. The quantity of water admitted to the wheel by the guides is regulated by the vertical rods c which, by means of a very simple contrivance, may be raised and lowered together at pleasure. The pivot which supports the vertical axis of the wheel, instead of being in the water, is placed above. In situations exposed to great and long-continued floods these wheels are constructed with a double system of guides and buckets as $a\,a'$, $b\,b'$, Fig. 7236; and by this means they may be easily adapted to the passing of very varying quantities of water.

Useful Effect.—From a vast number of experiments which have been made it has been found that when the vertical rods are raised so as to leave the openings of the directing vanes entirely free, the useful effect transmitted by this wheel will equal from ·68 to ·70 of the absolute work of the fall, and we shall have the formula $P\,v = 42 \cdot 4\,Q\,H$ to $P v = 43 \cdot 6\,Q\,H$. And when the rods are lowered so as to reduce the quantity of water discharged in the proportion of 4 to 3, the useful effect will not fall below ·575.

Example.—What is the useful effect given by a wheel of this class under the conditions $Q = 9 \cdot 4$ cub. ft. and $H = 5$ ft.? The rods being raised so as to allow of the maximum discharge of water, we shall have by the foregoing rule $P\,v = 42 \cdot 4 \times 9 \cdot 4 \times 5 = 1992 \cdot 8$.

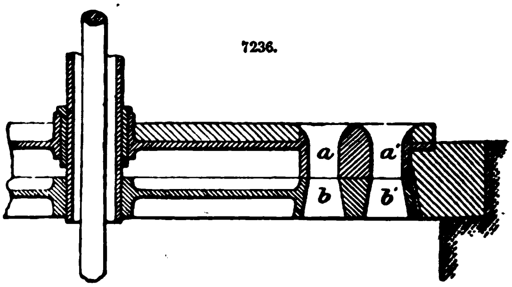
Construction.—If the volume of water Q is not known, it may be calculated by the formula $Q = \frac{P v}{42 \cdot 4 H}$, the notation of which has already been given.

7235.



The turbine should be so placed that the under side of the wheel is a short distance above the usual level of the tail water.

7236.

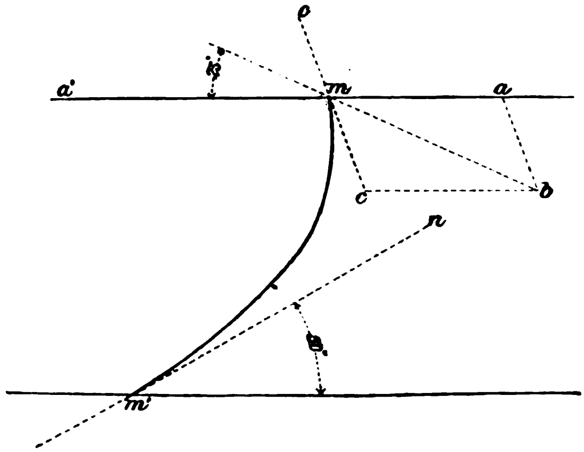


The thickness a of the sheet of water passing between the directing vanes should not exceed $2 \cdot 4$ to $3 \cdot 1$ in. for large volumes of water, usually it is limited to $1 \cdot 6$ or $2 \cdot 0$ in.; and the angle made by the mean fluid vein with the upper surface of the wheel will be 25°. The number n of the guides will be half the number n' of the buckets, and we shall have $n' = 2\,n$. The length e of the supply channels, measured in the direction of the radius, will be equal to three or four times the thickness of a; but where the quantity of water discharged is very great, this length may be still further increased. The guides being generally of cast iron they will occupy on the circumference of the fixed portion of the turbine a thickness of about $\cdot 4$ in. The portion l of the mean circumference corresponding to the lower side of each supply channel will be found by the formula $l = \frac{a + \cdot 4}{\sin. 25^\circ} = \frac{a \times \cdot 4}{\cdot 423}$. The number n of the supply channels will be $n = \frac{Q}{42 \cdot 4\, a\, e \sqrt{64 \cdot 4 H}}$. The mean radius R will be calculated by the formula $R = \frac{n\, l}{6 \cdot 28}$. On each side of this circumference, lay off in the direction of the radius, $\frac{1}{2}\, e$, and the circles drawn through the points thus obtained will give the width of the directing vanes and the upper side of the buckets; the lower side of the buckets should be increased by at least $\cdot 1$, in order to allow of the free discharge of the water. The thickness of the sheet of water flowing from the buckets of the wheel, or their shortest distance a' from the under side of one bucket to the next, will be $\frac{1}{2}\, a$, the sheet of water flowing between two consecutive directing vanes or guides. The angle formed by the buckets with the under side of the wheel should be about 30°. The height of the wheel h', not including the guides, will be three or four times the thickness a.

Mode of delineating the Buckets.—The velocity U of the water upon the turbine being given by the formula of approach $U = \cdot 9 \sqrt{2 g H}$, the velocity of the mean circumference of the wheel will be $V = 6 \sqrt{2 g H}$. Draw through the point m, Fig. 7237, situate on the mean circumference

of the wheel, a line making with the horizon an angle of 25°; mark off on this line a length $m b$, representing to a certain scale the velocity U. Upon the horizontal passing through the same point m, lay off the length $m a = V$, and construct the parallelogram $m a b c$, of which the side $m c$ will represent the direction and the value of the velocity of the water, requisite to bring it without shock, upon the buckets; and the mean profile of the bucket will be an arc of a parabola passing from the point m tangentially to the line $m c$, and joining the under side of the wheel at m', where it is tangential to the line $m' n$ making with the horizon an angle of 30°. The axis of this parabola may be found by the proportion $m\ P = \dfrac{h \text{ tang. } 30°}{\text{tang. } 30° + \text{tang. } c' m a'}$, in which h is the height of the turbine, not including the guides, and the angle $c' m a'$ is furnished by the trace. Knowing the axis of the parabola it will be easy to complete the curve. The profile thus determined is that which corresponds to the mean circumference of the wheel, and when the wheel is narrow the same profile may be adopted for the sides. When, however, the length c is considerable, it is better to draw, by the same method, the profiles corresponding to the outer and inner circumferences as well as the mean profile.

7237.



Example.—Let it be required to construct a double turbine under the following conditions. The quantity of water to be discharged in ordinary times is 57 cub. ft., with a fall of 10 ft.; in the time of floods the water is increased to 85 cub. ft. while the fall is reduced to 7 ft.

The total force will equal in ordinary times $57 \times 62 \cdot 32 \times 10 = 36522$ foot pounds, and in times of flood $85 \times 62 \cdot 32 \times 7 = 37073$ foot pounds.

For the proportions of the exterior wheel, which is worked by itself under ordinary conditions, we shall have $n a e = \dfrac{Q}{\cdot 68 \sqrt{2 g H}} = \dfrac{57}{\cdot 68 \sqrt{64 \cdot 4 \times 10}} = 3 \cdot 3$ sq. ft. If we take $a = 2 \cdot 4$ in. $= \cdot 2$ ft., $e = 3 a = 7 \cdot 2$ in. $= \cdot 6$ ft., we shall have $n = \dfrac{3 \cdot 3 \text{ sq. ft.}}{\cdot 2 \text{ ft.} \times \cdot 6 \text{ ft.}} = 27 \cdot 5$, from which we take the nearest whole number $n = 28$. For the length of the arc of the mean circumference occupied by each directing vane or guide we shall have $l = \dfrac{a + \cdot 4 \text{ in.}}{\sin. 25°} = \dfrac{2 \cdot 4 \text{ in.} + \cdot 4 \text{ in.}}{\cdot 423} = 6 \cdot 62$ in.; and from this $R = \dfrac{28 \times 6 \cdot 62}{6 \cdot 28} = 2 \cdot 46$ ft. The number of the buckets of the wheel will be $n' = 2 n = 56$, and their shortest distance on the lower side $a' = \dfrac{a}{2} = 1 \cdot 2$ in., with a length $e' = 1 \cdot 1 e = 1 \cdot 1 \times 7 \cdot 2 = 7 \cdot 9$ in. The exterior radius of the directing vanes and of the upper side of the wheel will be $29 \cdot 5 + \dfrac{7 \cdot 2}{2} = 33 \cdot 1$ in. The velocity V of the mean circumference in feet a second will be $V = \cdot 6 \sqrt{2 g H} = \cdot 6 \sqrt{64 \cdot 4 \times 10} = 15 \cdot 23$ ft.; and the number of revolutions made by the turbine in one minute will be $N = \dfrac{60\ V}{6 \cdot 28\ R} = \dfrac{60 \times 15 \cdot 23}{6 \cdot 28 \times 2 \cdot 46} = 59 \cdot 15$.

To determine the dimensions of the inner wheel, when the height of the fall is reduced to 7 ft., it must be borne in mind that the quantity of water passing through the outer wheel being $Q = \cdot 68 \times 28 \times \cdot 2 \times \cdot 6 \sqrt{64 \cdot 4 \times 7} = 48 \cdot 62$ cub. ft., the volume received by the inner wheel will be 85 cub. ft. − 48 cub. ft. = 36·38 cub. ft. Making $a = 2 \cdot 4$ in., $e = 4 a = 9 \cdot 6$ in.; then $n a e \dfrac{36 \cdot 38}{\cdot 68 \sqrt{64 \cdot 4 \times 7}} = 2 \cdot 5$ sq. ft., and we shall have $n = \dfrac{2 \cdot 5 \text{ sq. ft.}}{\cdot 2 \text{ ft.} \times \cdot 8 \text{ ft.}} = 15 \cdot 6$; and taking the nearest whole number $n = 16$; $l = \dfrac{a + \cdot 4 \text{ in.}}{\sin. 25°} = \dfrac{2 \cdot 4 \text{ in.} + \cdot 4 \text{ in.}}{\cdot 423} = 6 \cdot 62$ in.; and $R = \dfrac{16 \times 6 \cdot 62}{6 \cdot 28} = 1 \cdot 4$ ft.

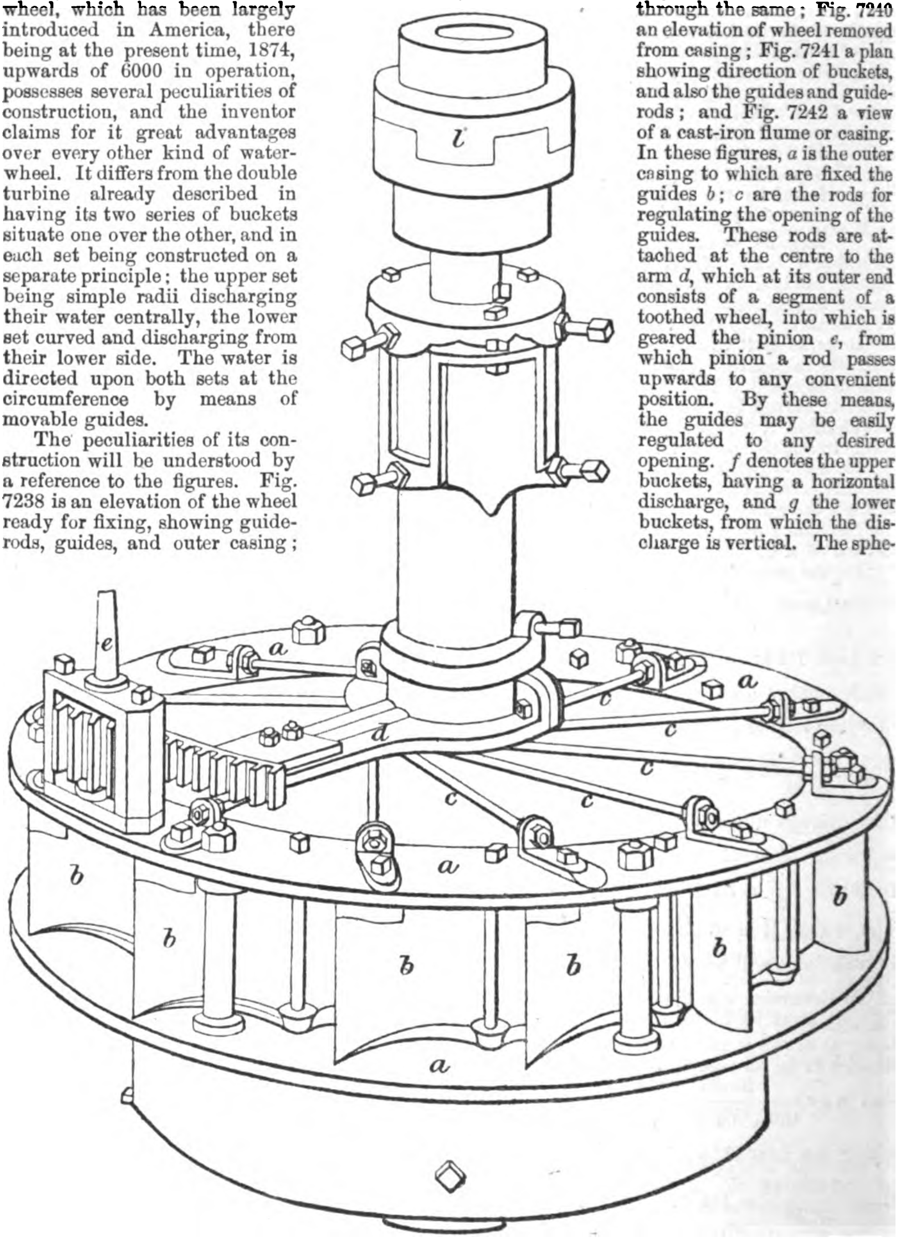
The velocity of this wheel may be varied within certain limits on either side of that corresponding to the maximum effect, without the proportion of the useful to the absolute work diminishing in any marked degree. The maximum force which this wheel can exert rises to 1·48 times that corresponding to the maximum effect for the same openings of the guides. The employment of a double system of guides and buckets renders this wheel particularly suitable for situations where the volume of water is very variable, as it provides for the discharge of large quantities in times of floods, without any resulting inconveniences when the supply is small. The improvement of

substituting for the vertical rods a flexible band which permits the entire opening of any number of guides while the others remain closed, does away with the disadvantage of partial openings and renders the action of the wheel more uniform under all conditions of water. The erection of this wheel does not present any great difficulties, and requires few hydraulic constructions. The pivots being placed above their water, can at any time be examined and oiled with little trouble. A governor may be used, provided that the guides are not entirely opened. This may therefore be classed as one of the best forms of turbine.

Leffel's Double Turbine.—This wheel, which has been largely introduced in America, there being at the present time, 1874, upwards of 6000 in operation, possesses several peculiarities of construction, and the inventor claims for it great advantages over every other kind of water-wheel. It differs from the double turbine already described in having its two series of buckets situate one over the other, and in each set being constructed on a separate principle; the upper set being simple radii discharging their water centrally, the lower set curved and discharging from their lower side. The water is directed upon both sets at the circumference by means of movable guides.

The peculiarities of its construction will be understood by a reference to the figures. Fig. 7238 is an elevation of the wheel ready for fixing, showing guide-rods, guides, and outer casing; **Fig. 7239 is a vertical section** through the same; Fig. 7240 an elevation of wheel removed from casing; Fig. 7241 a plan showing direction of buckets, and also the guides and guide-rods; and Fig. 7242 a view of a cast-iron flume or casing. In these figures, *a* is the outer casing to which are fixed the guides *b*; *c* are the rods for regulating the opening of the guides. These rods are attached at the centre to the arm *d*, which at its outer end consists of a segment of a toothed wheel, into which is geared the pinion *e*, from which pinion a rod passes upwards to any convenient position. By these means, the guides may be easily regulated to any desired opening. *f* denotes the upper buckets, having a horizontal discharge, and *g* the lower buckets, from which the discharge is vertical. The sphe-

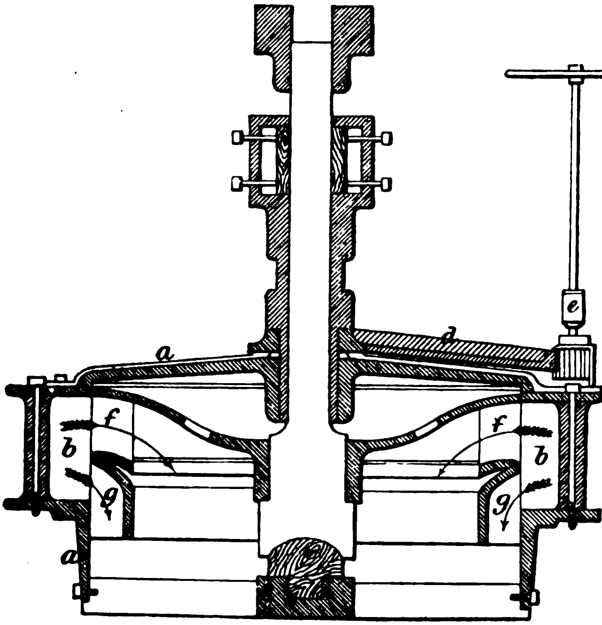
7238.



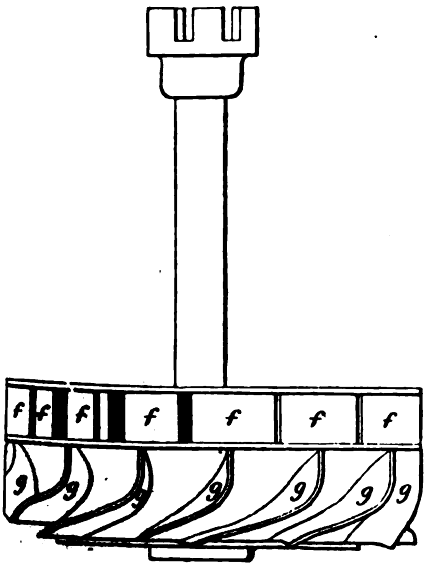
rical iron flume or penstock, Fig. 7242, is cast in two portions, and firmly bolted together so as to be perfectly air and water tight; it is furnished with a movable cap or cover *h* sufficiently large to allow of the wheel being removed bodily if from any cause such an operation should become necessary. In the cap is a hand-hole *i*, and in the sides, two large man-holes *k*, by means of which the wheel can at any time be examined, and any dirt or rubbish, which from carelessness or other cause has got there, may be removed. At the side is a short pipe having a flange by which it is joined

to the supply pipe or wooden penstock, and at the bottom is another short pipe through which the water makes its escape after being discharged from the wheel; the lower end of this pipe should be

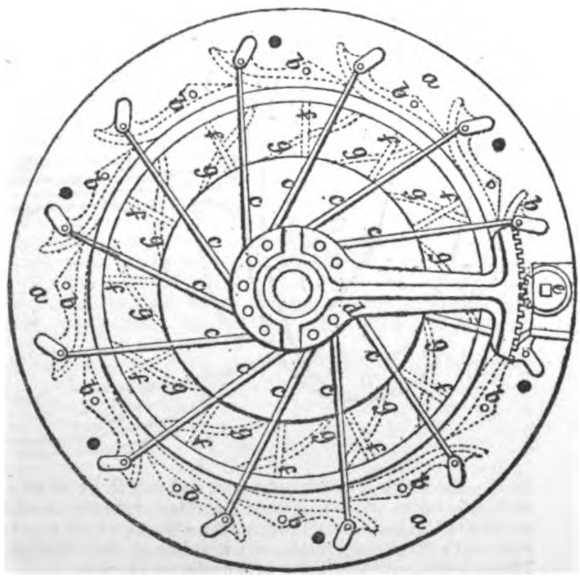
7239.



7240.



7241.



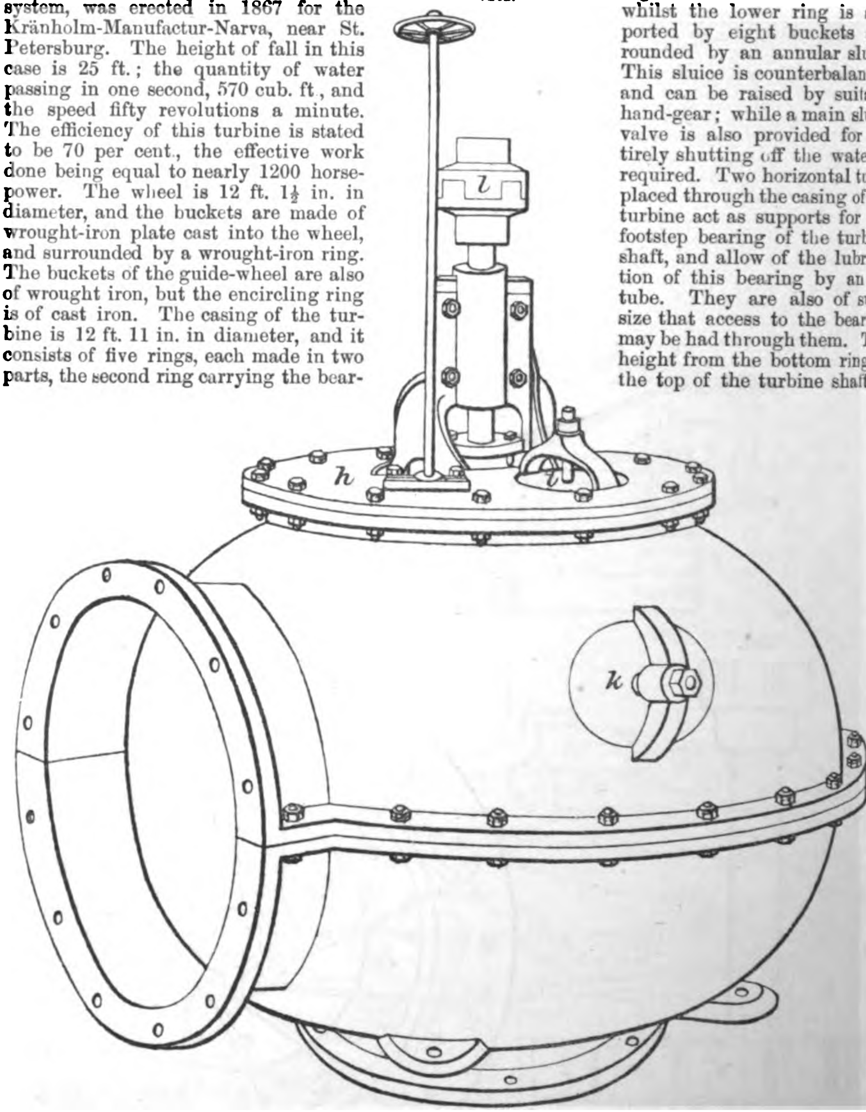
placed about 1 in. below the surface of the standing tail-water. To the top of the cover *h* is firmly bolted a bridge-tree for the support of the upper end of the water-wheel shaft, to which is attached a clutch coupling *l*. The water-wheel shaft and the guide-rod both pass through water-tight stuffing boxes.

The advantages claimed for this wheel are, that by the use of two sets of buckets, each having an independent discharge, provision is made for the maximum discharge of water with the minimum of friction, and that therefore the percentage of work will greatly exceed that obtained from any other wheel. It would appear, however, that the principal use of the upper buckets will be to provide an easy outlet for a large body of water without in any way extracting from it a due proportion of work. The makers lay great stress upon the amount of care which is bestowed upon the manufacture of these wheels, and the high finish which is given them. These, of course, are conditions

which would greatly improve the action of any wheel, and it may be that the esteem in which the Leffel wheel is held is due rather to these conditions than to any special advantage afforded by the peculiar arrangement of the buckets.

A turbine, on the Herschel-Jonval system, was erected in 1867 for the Kränholm-Manufactur-Narva, near St. Petersburg. The height of fall in this case is 25 ft.; the quantity of water passing in one second, 570 cub. ft., and the speed fifty revolutions a minute. The efficiency of this turbine is stated to be 70 per cent., the effective work done being equal to nearly 1200 horse-power. The wheel is 12 ft. 1½ in. in diameter, and the buckets are made of wrought-iron plate cast into the wheel, and surrounded by a wrought-iron ring. The buckets of the guide-wheel are also of wrought iron, but the encircling ring is of cast iron. The casing of the turbine is 12 ft. 11 in. in diameter, and it consists of five rings, each made in two parts, the second ring carrying the bearing for the axis of the turbine, whilst the lower ring is supported by eight buckets surrounded by an annular sluice. This sluice is counterbalanced, and can be raised by suitable hand-gear; while a main sluice valve is also provided for entirely shutting off the water if required. Two horizontal tubes placed through the casing of the turbine act as supports for the footstep bearing of the turbine shaft, and allow of the lubrication of this bearing by an oil tube. They are also of such size that access to the bearing may be had through them. The height from the bottom ring to the top of the turbine shaft is 38 ft.; the latter is of wrought iron and is 1 ft. 3¾ in. in diameter. The bevel-wheels by which the motion is taken off, are 12 ft. in diameter, and each is made in two parts bolted together. The total weight of the turbine is 14 tons. The works which this turbine assists in driving comprise a cotton mill, with 239,692 spindles, and weaving sheds containing 1647 looms. It was constructed by the Maschinenfabrik-Augsburg, of Augsburg, Bavaria.

7242.



TURN-TABLE. Fr., *Plaque tournante*; Ger., *Drehscheibe*; Ital., *Piattaforma girante*; Span. *Plataforma*.

See Permanent Way. Railway Engineering.

TUYERE. Fr., *Tuyère*; Ger., *Form*; Ital., *Foro del vento*; Span., *Tobera*.

See Blast Furnace. Iron.

UNDERSHOT-WHEEL. Fr., *Roue en dessous*; Ger., *Unterschlächtiges Wasserrad*; Ital., *Ruota a palette di sotto*; Span., *Rueda de paletas*.

See Float Water-wheel. Hydraulic Machines, Varieties of.

UNIVERSAL JOINT. Fr., *Joint universel*; Ger., *Universalgelenk*; Ital., *Snodo universale*; Span., *Junta universal*.

See Joints.

VELOCITY. Fr., *Vitesse;* Ger., *Geschwindigkeit;* Ital., *Velocità;* Span., *Velocidad.*
The speed with which a body is moving is termed its velocity. If the body moves uniformly, this may evidently be measured by the quotient of the space divided by the time. Thus the velocity 30 miles an hour would be represented by 30 if the units be miles and hours. When the movement is not uniform, the velocity is measured by the space described in an infinitely small time, divided by the time. Thus $\frac{ds}{dt}$ is the measure of velocity. See Angular Motion.

VENTILATION. Fr., *Aérage;* Ger., *Luftwechsel;* Ital., *Ventilazione;* Span., *Ventilacion.*
Ventilating and Warming.—As ventilating and warming are kindred subjects, intimately connected in practice, we have preferred to include them in one article; but for greater clearness and simplicity we shall investigate the questions relating to each separately.

Ventilation consists in the removal of all vitiated air from an apartment and in the replacing of it by an equal quantity of pure air. To appreciate fully the necessity of this operation, it is requisite to understand the composition of atmospheric air and the causes of its vitiation.

Atmospheric air, in its normal or pure state, is composed of oxygen and nitrogen in the proportion of 21 to 79; it also contains a few thousandth parts of carbonic acid, a variable quantity of vapour of water, and a little carburetted hydrogen. Schœnbein, of Basle, in 1840, and more recently Houzeau, of Rouen, have proved that the atmosphere contains ozone also, in the very small proportion of $\frac{1}{1400000}$ it is true, but varying according to situation. Thus in large cities it disappears altogether; while its presence is very appreciable in the country, especially on the tops of hills and in the depths of forests. No doubt this is one of the chief causes of the salubrity of country air. It has been remarked that when the wind blows from the south-west, the air contains its maximum quantity of ozone, and that at such times the mortality is low. Many careful and delicate observations have yet to be made to complete our knowledge of this agent; but enough has been learned respecting it to show that it plays an important part in preventing and arresting the progress of fermentation, and consequently in promoting the salubrity of the atmosphere. Agricultural chemistry teaches us that the atmosphere always contains a variable quantity of nitrates and ammonia generated by the incessant decomposition of organized bodies. It is by bringing down these substances that rain fertilizes fallow ground, and in one manner acts beneficially on vegetation. The quantity is largest in the neighbourhood of large towns, where it is probably in excess. But as they exist everywhere in a greater or less proportion, we must consider these bodies as constituent parts of a pure atmosphere. It is only in recent years that the intimate composition of air and its actual influence upon health have been made subjects of careful investigation. Formerly it was deemed sufficient to consider it merely in relation to its temperature. This was one of the greatest errors committed in the matter of ventilation, and it is too often fallen into even in the present day.

Such is the atmosphere in its pure state. It is rare, however, that we find it free from polluting matters. When a ray of sunlight falls into a darkened room, it reveals to our sight myriads of vegetable and animal molecules which, under ordinary conditions, are invisible. These molecules are derived from the friction of bodies, the emanations caused by the progress of vegetation in plants, the respiration and transpiration of animals, and the combustion of vegetable, animal, and mineral substances. The air contains also the products of fermentation and effluvia of various kinds. When the air of towns, or even that of the open country, is analyzed, we find that it holds in suspension matters derived, not only from the soil, from animals and plants, but also from the surface of the sea, which matters are carried by the wind to very great distances. These myriads of microscopic germs play an immensely important part in the organized world. They are the agents of corruption, the sinister authors of disease, continually on the watch for an opportunity to insinuate themselves into the human organism to deposit their deadly poison. The researches of chemists and physicians, especially those of Faraday, have shown almost demonstratively that the worst epidemic diseases are due to these causes. Such facts are of themselves sufficient to render abundantly evident the necessity of providing our dwellings, and above all our hospitals, with an ample supply of pure air by means of a system of ventilation. But there are other causes of vitiation that are also of grave importance.

It has been ascertained that the average quantity of air inhaled by a person sitting still, or moving gently about a room, is 600 cub. in. a minute. This air, when expired, differs in several respects from what it was when inspired. Whatever its temperature may have been previous to inspiration, on quitting the lungs it has about the same temperature as the blood, that is, about 90° Fahr. Thus it is not surprising that several persons together in a room, in which the ventilation is deficient, speedily raise the temperature of the atmosphere in it, seeing that each pours into the limited atmosphere of the room 600 cub. in. of air at 90° every minute, irrespective of the heat which is given off his body by radiation. Also whatever degree of dryness the air may possess previous to inspiration, after expiration it is saturated with vapour of water. Nor are these the only changes that the air undergoes during its passage through the lungs. Another and a very important one is that a quantity of its oxygen, equal to 5 per cent., is absorbed, and its place supplied by an equal quantity of carbonic acid. Thus, a man in an air-tight room having the form of a cube of 6 ft. side will, in the course of twenty-four hours, have passed every particle of the air in it through his lungs, raised the temperature of the air to that of his own body, neglecting the quantity of heat abstracted by the walls, and seriously changed its composition by absorbing oxygen and substituting carbonic acid. The quantity of water which he will throw upon the atmosphere in the form of vapour will vary greatly according to the individual and the season.

The composition of the air is also changed by the combustion of lights, which also deprives the air of a portion of its oxygen and disengages carbonic acid; at the same time the solid products of combustion are thrown upon the air.

The preceding causes of vitiation may be described as internal, since they operate within the building to be ventilated. But we have in addition to these, external causes of vitiation, or causes

that operate out of doors, and which must always be taken into account in designing a system of ventilation, a necessity that is too frequently forgotten. The chief of these causes are the gaseous and solid products of combustion discharged from the chimneys of dwelling-houses and factories; the decomposition of animal matter; the decomposition and fermentation of vegetable matter in the fields and in the markets, streets, and back yards of towns; the gases and miasmata, due to the same source, which are discharged from sewers, and, of course, the internal causes which we have already described, and which are carried out into the external atmosphere. Against all these vitiating causes, nature has provided an efficient remedy in the absorption of the polluting matters by the vegetables, the health of which they tend to promote. Consequently, in the open country, unless the source of pollution be situate very near the dwelling, the external vitiation of the atmosphere may be safely neglected. But in towns, and especially in large towns, where these causes are multiplied and intensified, and where the absence of vegetation lessens the remedial influences provided in nature, it becomes a matter of serious importance, and one that must be carefully considered when estimating the quantity of air requisite for ventilative purposes. Hitherto this subject has been strangely neglected; in no work treating on ventilation that we are acquainted with, is it even mentioned. A certain number of cubic feet a minute for each person has been considered necessary both by writers and government commissioners, quite irrespective of locality. That such an opinion is altogether erroneous, the facts described above sufficiently show.

The causes of a vitiated atmosphere are so numerous, and many of them are so potent, that the necessity of a constant renewal of the air of an apartment is one of primary importance to health. This is especially the case in public buildings, where large masses of persons congregate, and in hospitals, in which the causes of vitiation are enormously intensified. But we need not enlarge upon a necessity the gravity of which is so obvious, and which is now generally recognized.

The modes of renewing the air of an apartment are few and simple. Heated air, as is well known, has a tendency to ascend. Advantage is taken of this fact to allow the heated and vitiated air to escape, its place being supplied by the denser external air. This may be described as the natural mode of ventilation, and is in general the most effective. Another mode is to exhaust the air from the apartment by means of a fan. This has been successfully applied to certain classes of public buildings; but it is not generally suitable. Simple as these means are, however, the application of them presents great, and in some cases insurmountable, difficulties. If it were merely a question of extracting the vitiated air and supplying its place with pure air, few things could be more easily effected. But the operation has to be performed without occasioning a perceptible draught, as the latter is as much to be dreaded as the foul air, and herein lies the problem. This problem evidently admits of only one solution, namely, by admitting the air through a passage having a widely-extended area, and situate at a considerable distance from the persons in the room. The best way of effecting this is to admit the cold air through a number of minute holes spread over a large space in or near the ceiling. A channel, for example, in communication with the outer air, is provided behind the cornice, and the air is allowed to enter the room through holes, or through long narrow openings covered with perforated zinc. When these conditions are properly complied with, the air can be admitted with a low velocity, and at such a distance above the persons in the room that no draught is felt. But in the fulfilment of these conditions, many difficulties, architectural and others, are met with. The former may be overcome; the latter are in many cases insurmountable. What these difficulties are we shall see when describing the various systems of ventilation. Two things may be mentioned here as militating seriously against every system, namely, the imperfection of structures, which allows the cold air to enter through the doors, windows, and crevices, thereby causing unpleasant draughts, and the necessary opening and shutting of doors, whereby the temperature of the room is suddenly lowered, and the direction of the currents changed. To remedy the latter evil, it has been proposed to construct double doors, similar to those used for the same purpose in mines; but though the plan fully answers the purpose intended, it has been found to be impracticable.

With respect to the position of the inlet and outlet apertures, there has been much controversy. Until recently it has been taken as a matter of course, that because heated air has a tendency to ascend, the aperture for its escape should be near the ceiling, and that the admission of the cold air should, on the contrary, be near the floor. This principle has been generally adopted in practice, with the disagreeable consequence of a cold draught along the floor. This notion respecting the ventilating currents is evidently due to a misconception concerning the motion of the heated air. The latter has of itself no tendency to ascend; but it rises because, having increased in volume under the expanding influence of heat, it is pushed up by the denser surrounding air. Now it is obvious that the denser fluid will exert the same force upon the less dense wherever its inlet aperture may be situate. Consequently, a better position for this aperture is near the ceiling, because, when so situate, the incoming air gets diffused in the atmosphere of the room before reaching the persons in it. It is also equally obvious, that the heated air will be forced as freely out at the bottom of the room as at the top, if we only provide that it shall escape into the atmosphere at a height not below that at which the cold air enters. Such a situation is therefore the best for the aperture of discharge; because when so placed, the air near the floor, which is always more or less cooled by currents entering beneath the doors, is kept at an agreeable temperature. Besides this, the heavy matters, such as carbonic acid gas, and the solid molecules floating in the atmosphere, are more readily and effectually swept away. This principle of ventilation, which rests upon indisputable facts, is being gradually substituted for the old and erroneous one still in very common use.

The quantity of air that should be passed through a room in a given time in order to keep the atmosphere in it in a proper state of purity is a question of primary importance. Authorities are not agreed on this matter. Thus Peclet, calculating from the quantity of carbonic acid produced, says 5 cub. ft. a minute of fresh air should be allowed for each person. Reid, calculating

from the quantity of fresh air required to carry off all the contaminations resulting from human life, says 10 cub. ft. The government commissioners say from 10 to 20; Morin, 15 to 20, and Arnott and Roscoe, 20. The quantity of air actually inhaled by a person when sitting still, or moving gently about a room, is about half a cubic foot a minute. The miasmata or effluvia derived from the various secretions of the body, which, as we have already said, constitute the most potent and dangerous cause of vitiation in the atmosphere, will require, say 1 cub. ft. a minute, for we can estimate this vitiating cause only approximatively. This allows a film or covering of air $\frac{3}{4}$ in. thick over his whole body, which film is changed every minute. But when undergoing moderate physical exertion, or when heated by crowding in a public room, the quantity of air breathed is nearly 1 cub. ft. a minute; and as the poisonous emanations from the body are increased in a like degree, we may assume that 3 cub. ft. a minute is the minimum quantity of fresh air requisite for each person. This minimum quantity is, however, calculated on the assumption that at the expiration of the minute the air fouled during that time is instantly and completely removed from the room. Such is far from being the case, and to take this fact into account, we must double the quantity previously found. Moreover, it will be necessary to provide a sufficient margin to allow for interruption of the ventilation and unforeseen contingencies. The factor of safety to give this margin should not be less than 2. This gives us as the requisite quantity of fresh air for each person 12 cub. ft. a minute. We have already explained that the atmosphere of towns is less pure than that of the open country; this fact must be taken into account when estimating the requisite quantity of air, for when the fresh air is itself vitiated, a larger quantity must be passed through the room. Therefore, in calculating the ventilation, 12 cub. ft. a minute for each person should be allowed in the open country, 15 cub. ft. in small towns, and 18 cub. ft. in large towns.

A candle or small lamp heats the air and fouls it with the products of combustion to a degree requiring 1 cub. ft. a minute, and an ordinary full-size gas-burner eight times as much. According to the Blue Book, an ordinary open fire-place requires about 1000 cub. ft. of fresh air a minute. All of these causes of vitiation must be duly allowed for in calculating an adequate ventilation. To illustrate the application of these principles, suppose we have to ventilate a private room, say a dining-room, calculated to accommodate fifteen persons, and having four gaslights and one fire. The quantity of air necessary to keep the atmosphere of this room in the requisite state of purity, will be for the country $(12 \times 15) + (8 \times 4) + 1000 = 1212$ cub. ft. a minute; for the small town $(15 \times 15) + (8 \times 4) + 1000 = 1257$; and for the large town $(18 \times 15) + (8 \times 4) + 1000 = 1302$ cub. ft. a minute. As the fresh air entering should never have a velocity greater than 3 ft. a second, the total area of the orifices through which it is admitted will in this case be 6·75, 7, and 7·25 sq. ft. respectively. The velocity of the air in the channels leading to these orifices may, of course, be much greater than 3 ft. a second; but it should be kept down to the lowest possible limit. If these dimensions be given to the inlet apertures, very little cold air will force itself in through the doors and windows; and if the apertures be situate near the ceiling and widely distributed, no draught will be felt in any part of the room.

No system of ventilation can be considered perfect that allows the fresh air to enter at the same temperature as that of the external air, and experience has shown that no such system can be successful even in effecting an adequate ventilation by reason of the opposition it meets with. In our climate the outside air is too cold during seven months of the year to admit of its being introduced directly into our apartments. The dangers of the cold current are as great as those of imperfect ventilation; for while the latter brings fevers, cholera, and diseases of a similar character, the former brings colds, rheumatism, bronchitis, and consumption. For this reason, as well as from the discomfort which cold draughts occasion, it has been found that when the incoming air is not previously warmed, the apertures are speedily closed up, the occupants of the apartment preferring stuffiness to cold. This condition of warming the air previous to admission greatly complicates the problem of ventilation, but it must be considered as essential to any system.

One effect of heat upon air is to raise its point of saturation. One cubic foot of air, say at 32°, is capable of containing a certain quantity of moisture, and no more. But if we raise its temperature to 80°, which is near that of the human body, it is capable of containing five times as much, and consequently it absorbs moisture from everything that contains any. This heating of the air does not dry it in the sense of extracting moisture from it; it only increases its capacity of containing water, thereby rendering it more absorbent or thirsty. Air suddenly heated is thus rendered unwholesomely dry, and this is an important point in regard to the subject of warming, requiring careful consideration. Whenever the fresh air is warmed before being admitted into a room, an evaporating pan, or some other means, must be provided to supply the air with the necessary degree of moisture.

We shall now consider the various modes of applying the foregoing principles to the ventilation of different classes of buildings.

The atmosphere of a room may be renewed by one of three means, or by a combination of any two of them; fire suction, that is, by placing the room in communication with a flue, at the bottom of which a fire is kept constantly burning; mechanical suction, which is produced by means of a fan placed at the outlet; and propulsion, which is effected by means of a fan or pump placed in communication with the inlet. Each of these means possesses advantages that render it suitable according to the character of the building and the object sought.

The advantages of fire suction are, that it is the most simple and natural mode of ventilation; it does not require, as the other systems do, the attention of special attendants; it extracts the vitiated air directly from the point where it is produced; and it is the most economical, since in no case can the cost exceed that of the fuel consumed, and in most cases this can be reduced to a very small quantity by utilizing the heat of the ordinary fires. On the other hand, it has been urged against this mode of ventilation, that it interferes with the draught of the chimneys, draws into the room the smells from the kitchen and other offices, mingles the emanations of the patients in hospitals, and necessitates flues of large dimensions. Most of these disadvantages, however, are due

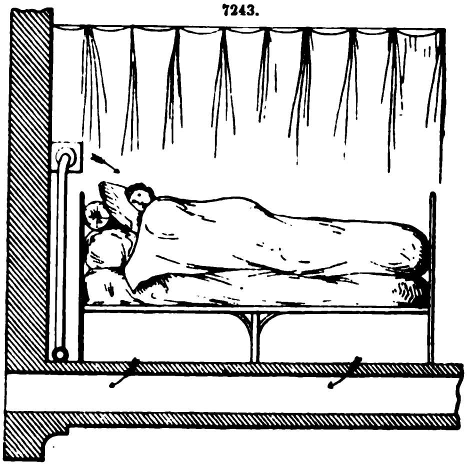
rather to a defective arrangement than to the nature of the system itself, and might be obviated by greater attention to details.

For the mode of ventilation by injection, it is claimed that the quality and quantity of the air admitted may be better regulated, that it may be directed to the spot required, that the risk of fire is lessened, and that the cost of tall up-cast shafts is saved. Evidently the advantages of both modes are considerable, and neither can be condemned as absolutely inferior to the other. Fire suction is far more generally applicable than any mechanical contrivance; but the latter may, in some cases, be far more effective. Circumstances will always determine the choice.

The Ventilation of Hospitals.—The ventilation of hospitals is subject to conditions essentially different from those which have to be complied with in other public buildings. Here the causes of vitiation are more numerous and much more serious. The virulent effluvia rise to every part of the ward, insinuate themselves into every crevice of the ceiling or floor, and hang about the curtains and bedding. Thus it is necessary, not only that the ventilative current should be abundant and reach every portion of the apartment, but that it shall not carry the emanations from one patient to the next; in other words, the ventilation must be so carried out that each patient shall be freed from his own emanations and protected from those of his neighbour.

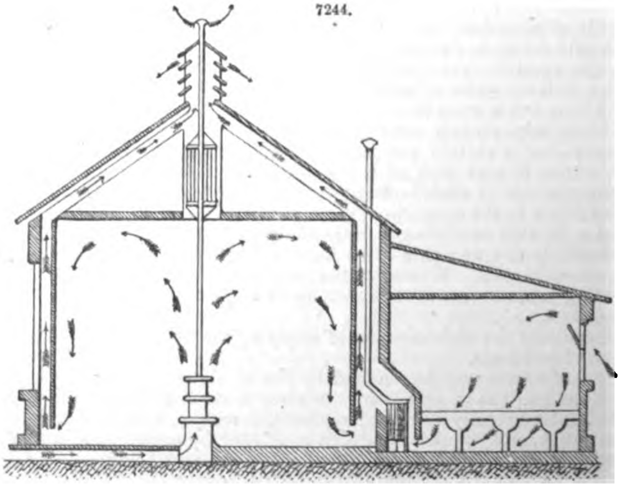
One method of fulfilling these conditions, which has been very successfully employed in the United States, is shown in Fig. 7243. In this method the fresh air is admitted to the patient through a long narrow aperture covered with a perforated plate, situate a little above his head, and

7243.



7243*.

7244.



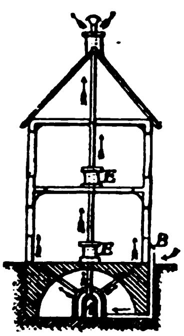
taken out beneath the bed through an aperture in communication with a suction-flue. This is one of the cases in which insufflation may be advantageously combined with suction. Fig. 7244 is another American example of hospital ventilation, very similar in general arrangement to that carried out in many European institutions. The fresh air, after being heated by a stove, first ascends to the ceiling, and is then drawn down to apertures near the floor by smoke-flues under the roof. The wards, in this case, are of one story only.

In the designing of a new building, care should be taken to provide for a thorough system of ventilation, the wholesomeness of the structure being of more importance than its artistic appear-

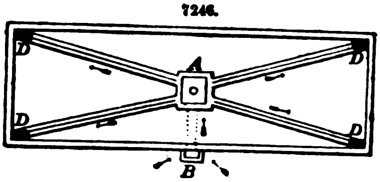
ance. In the case of a hospital, above all others, the laws of health should take precedence of the laws of beauty. If this necessity be borne in mind by the architect, there is not much difficulty in adopting the most suitable and efficient system. But in the case of old buildings the difficulty is much greater, and it often becomes necessary to modify a system in order to adapt it to the circumstances in which we find ourselves placed.

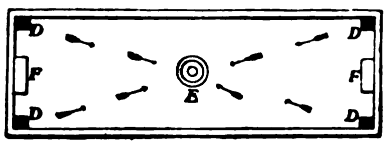
An arrangement generally applicable, with slight modifications, to existing buildings, is shown in the accompanying figures. Fig. 7245 is a cross-section of the building; Fig. 7246 a plan of the basement, and Fig. 7247 a plan of a floor. A heating apparatus A is placed in the basement in the centre of the building; fresh air is supplied to the apparatus through gratings at B, a hollow cover C, Fig. 7248, being provided to prevent waste of heat. The air enters this cover at the bottom,

7245.



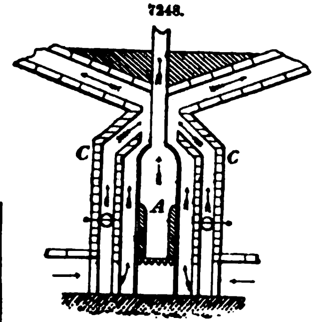
7246.





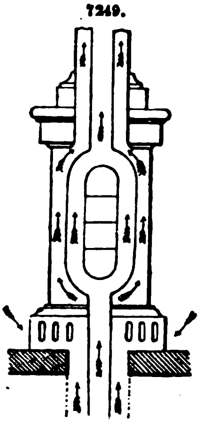
7247.

7248.

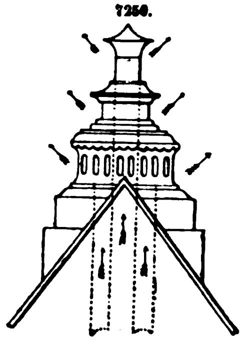


and its passage is regulated by a regulating disc. Four air passages or ducts from the upper angles convey the heated air to the corners D, where the circulation is usually very languid; it is then drawn to the middle of the apartment towards the smoke-flue E, where it is sucked downwards, so as to equalize the temperature. Fig. 7249 shows the stove placed in the middle of the apartment to draw away the vitiated air. The stove on the second floor, as well as its ventilating pipe, will necessarily be divided to keep the vitiated air of the two floors separate. Both the smoke and air flues are brought out at the top of the roof in the manner shown in Fig. 7250; this external portion may be either of galvanized iron, or if more ornament be desired, terra-cotta.

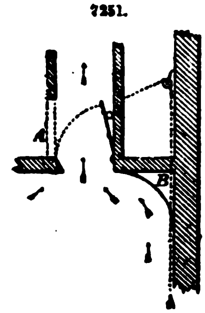
7249.



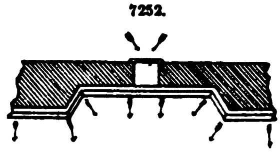
7250.



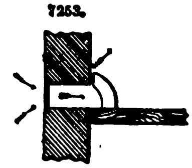
7251.



7252.



7253.

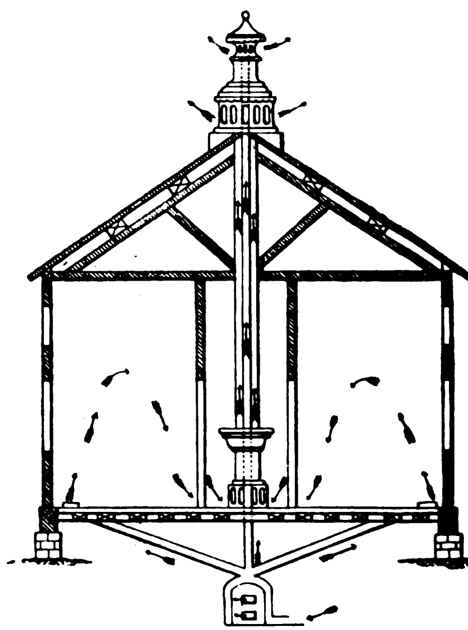


These arrangements are designed for warming and ventilating in winter. To render them perfect, there should be for the ventilation in summer two ventilating fire-places at the points F on each floor. Small trap openings should also be provided in the ceiling, capable of being opened and closed by a cord, and communicating with a flue, terminating above the roof, with a cowl to protect it from the rain and wind. Fig. 7251 shows the arrangement of one of such traps; a door or manhole A is provided to give access to the trap. The angles of the ceiling and walls should be rounded at B to prevent the accumulation of effluvia in those parts which are not swept by the ventilating current. A gas jet should be kept burning in the air-flue to promote the circulation. A common mode of admitting the air, adopted in some of the London hospitals, is shown in Figs. 7252, 7253. It consists of a kind of skirting, applied to the lower angles of the room, the air being

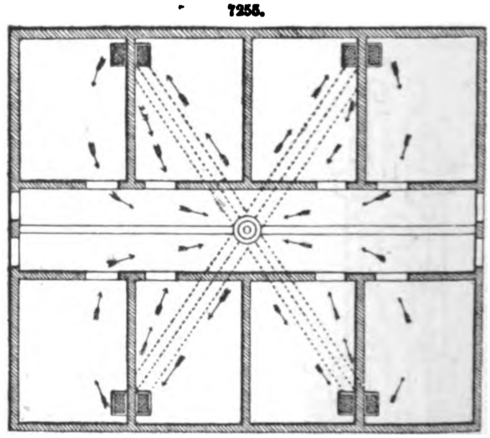
introduced behind the skirting, directly from the outside, and allowed to enter the room in the manner represented in the figures.

A modification of the plan of ventilating a hospital described above has been proposed by M. Joly, to whose excellent work we owe some of the illustrations given in this article. The arrangement is shown in Figs. 7254, 7255, in which the building is separated into two portions to isolate the sexes. Here the same system of warming and ventilating may be employed, whatever the number of separate wards may be. The heating apparatus is situate as before in a central part of the basement, and air-ducts convey the warm air to each apartment. The ducts are provided with regulators to cut off the current or to lessen it when the apartment is unoccupied. The air is admitted near the outer wall, and is allowed to escape through the bottom of the door, which is perforated for that purpose, the suction being effected in precisely the same way as already described. To this principal building will be joined the usual dependencies, as doctors' and nurses' room, bath-room and kitchen, the smoke-flues of which will be utilized to draw away downwards the effluvia from the water-closets.

7254.



7255.

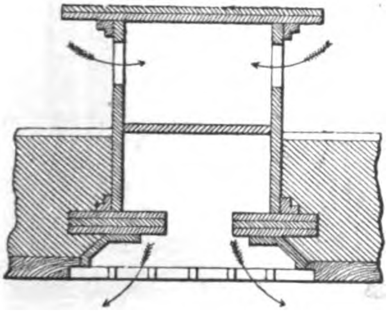


Three examples of London hospitals may be taken as illustrations of the most recent modes of ventilating these institutions,—the new infirmary of the Wandsworth and Clapham Union, Guy's Hospital, and St. Thomas's Hospital. The ventilation of the new infirmary is wholly natural, that is, no special fires nor mechanical means are employed. The ward which we shall take as an example of the whole is 123 ft. long, by 24·5 ft. broad, by 12 ft. high. Two upright chimney breasts, each having two open fire-places, one on each side in the length of the ward, stand out in the centre of the room, equidistant from the ends. A flue, in communication with the outer air, runs along beneath the floor and into a chamber at the back of the stove. The air thus introduced is admitted warm into the wards through the front and upper part of the stove. Immediately above these openings are others exactly similar, which also communicate with the air outside, but in a totally different direction. The smoke-flues are constructed on the principle of having at each angle of the circular flue a small air-flue, which in this case runs up to a chamber specially built in the roof, and enclosed on all sides by gratings of terra-cotta. By this means a constant down-draught of fresh air is obtained into the ward. In each pier between the windows is a Sheringham ventilator, communicating directly with the outer air, and regulated by lines, under the control of the nurses. To get rid of the heavy gases which are generated in disease, and which, if undisturbed, accumulate under the bed, an ordinary ventilator, opening directly into the outer air, is fixed under the head of each bed. By opening this for a few minutes at a time, the gases are quickly dispersed and carried off through the ordinary outlets for the foul air. In addition to all this, there are flues in the external walls running up to the roof and opening into the wards by self-acting valves. These flues are calculated at 1 in. of area for every 50 cub. ft. of air contained in the ward. They lead up into the open space within the roof, which is furnished with louvres at the ridge, through which the foul air finally escapes. This has been described as one of the most perfect of modern systems of ventilation. How far it is in accordance with the principles we laid down at the beginning of this article, our readers must be left to judge. We cannot refrain, however, from censuring the highly pernicious plan of allowing deadly gases to accumulate under the beds and then dispersing them among the patients by a set of ventilators specially provided for that purpose.

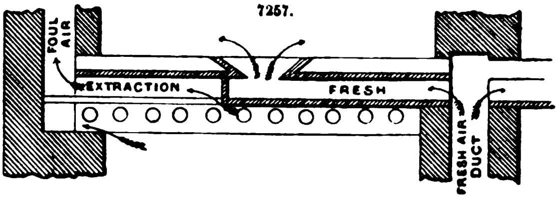
At Guy's Hospital the system adopted is more rational. Two lofty down-cast shafts, one on each side of the principal entrance, communicate with a chamber in the basement. An up-cast shaft for the discharge of the vitiated air and the smoke is placed near the centre of the building and at a

considerable distance from the down-casts. The height of this up-cast is also considerably greater than that of the others. The fresh air passes directly down into the basement, where it is heated by means of hot-water pipes. It then ascends through numerous flues in the brick piers in the centre of the wards. To admit it into the wards, the box girders that carry the floors are made use of, and the same means are employed to carry off the vitiated air. The mode of effecting this will be best seen by a reference to Figs. 7256, 7257. The upper flue is imbedded in the concrete of the floor, and admits the fresh air through gratings; the lower flue is below the ceiling of the ward, and receives through a number of circular openings the vitiated air of the ward below, which air is carried by a series of independent flues into a foul-air chamber, situate beneath the roof, from whence it is conveyed to the great up-cast. In a portion of the building erected a few years ago, the air is admitted at the ceiling and carried off through gratings near the floor at the head of each bed. In this respect the old is the better arrangement.

7256.



7257.



At St. Thomas's Hospital, which is the largest and the most recently erected of the London hospitals, the system of ventilation carried out partakes of the character of both the preceding. Taking a single ward as an example of the whole, we find three fire-places in the centre facing the end of the ward. An iron extraction-flue encloses the smoke-flue of each fire-place, the heat of the latter being thus rendered available in producing the suction. The vitiated air is taken into this up-cast flue through a grating at the level of the ceiling. As in the Wandsworth Infirmary, the fresh air is led in through a flue within the levels of the floor, which flue is in communication at one end with the external air, and at the other with a hot-air chamber behind the fire; in this way, it is warmed before being admitted into the ward. The building is divided into blocks, each floor of which constitutes a ward, with its necessary dependencies of lavatories, nurses' rooms, and kitchens. Each block is provided with its own set of hot-water apparatus, the furnace for which is situate in the basement story. The flue from this is carried up to the turret level in an iron tube forming the centre of an up-cast flue to the block. In addition to the open fires, there are on each floor two large coils of hot-water pipe, and to each coil fresh air is supplied by a separate air-duct running within the levels of the floor and communicating with the external air. At the ceiling and floor level there are gratings communicating with flues leading to the central up-cast connected with the smoke-flue of the hot-water apparatus in the basement. Thus we have as the means of introducing the fresh air to each ward, the flues communicating with the air-chambers behind the three stoves; and the flues communicating with the two hot-water coils. And as the means of extracting the vitiated air, we have the three up-casts surrounding the flues of the open fire-places and leading up to a chamber in the roof; and those connected with the larger up-cast enclosing the smoke-flue of the hot-water apparatus.

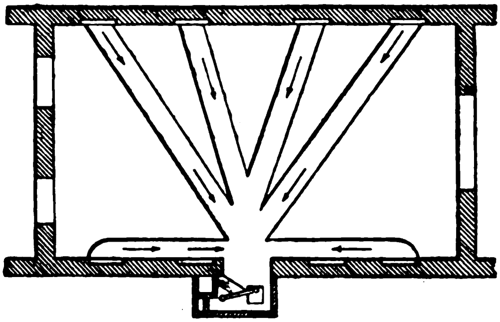
In the last two examples, the conditions of a good ventilation appear on the whole to be satisfactorily fulfilled. No doubt some of the details would admit of improvement, especially with regard to the precautions necessary to be taken to prevent the mingling of the emanations of different patients. But generally the arrangements are such as ought to give good results in maintaining the wholesomeness of the building.

The Ventilation of Schools.—Next to the ventilation of hospitals, that of schools demands the most careful attention. Here we have congregated together a large number of children in various states of health, and often in various conditions of cleanliness. The numerous and sudden ailments that children are liable to, and the heated state in which they usually arrive, render it doubly necessary that the ventilation of the schoolroom should be at all times ample and brisk, but free from cold draughts. The delicate organization of young children exposes them to great danger from the infections of vitiated air, and one means of lessening the difficulties of hospital ventilation is to diminish the number of patients by improving the ventilation of dwellings and schools. The most approved systems now in use are fairly illustrated by the following examples.

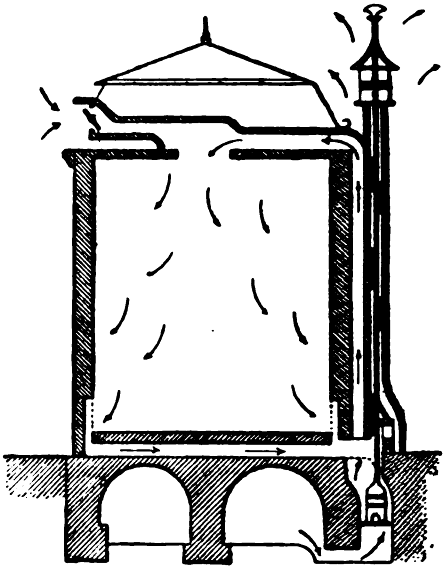
In the first example, which represents a system widely adopted on the Continent, we shall take one room as a specimen of the whole. The system, as shown in Figs. 7258, 7259, consists essentially of a heating apparatus, situate in the basement, when there is one, and in an adjoining room when there is no basement story; an air-chamber under the roof, and several extraction-flues beneath the floor leading to the smoke-flue of the heating apparatus. The fresh air, which is introduced at a point situate as far as possible from the top of the up-cast, passes round the stove, ascends vertically through a duct to the air-chamber in the roof, and is admitted to the room through the ceiling. To modify the temperature of the incoming air, a small quantity of cold air may be admitted to the air-chamber through an opening which in summer serves as the aperture

for the supply of fresh air, and which for this reason should be situate on the north side of the building and protected from the sun; at the same time it should be readily accessible. If the

7259.



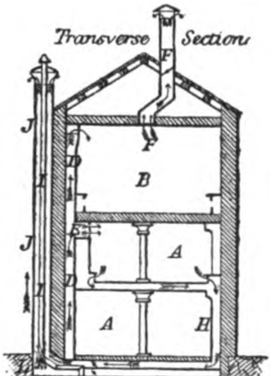
7258.



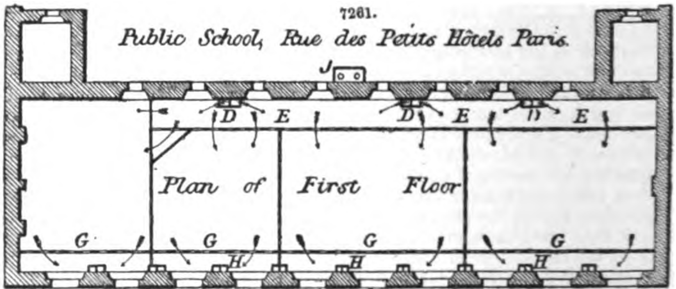
apertures for the admission of the air through the ceiling be sufficiently numerous and widely distributed, no draught will be felt. A small supplementary furnace in connection with the up-cast should be provided to assist the smoke-flue when a more powerful suction is rendered necessary. With a little care and attention on the part of the person in charge, this system works very satisfactorily. It is also a very economical one, a circumstance that has led to its adoption, with some modifications of detail, in many schools in the rural districts of the United States.

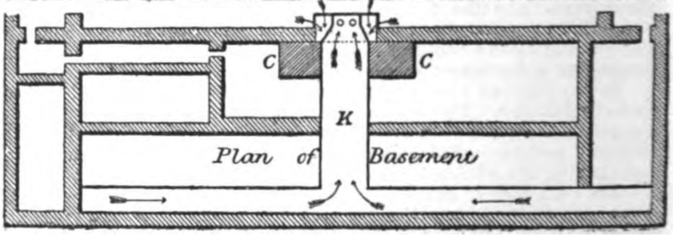
The accompanying Figs. 7260 to 7262 represent

7260.



7261.





7262.

the public school in the Rue des Petits Hôtels, Paris, and the system of ventilation therein adopted, as described by Morin. The building contains an elementary school, A A, for 400 children, and a drawing school, B, for 270 pupils. The ventilation is at the rate of 350 cub. ft. an hour to each pupil, and the warming is effected by two heating stoves C, C, with vertical tubes. The warmed air is supplied to each story by three vertical channels D, which discharge into a long wide passage E, extending the whole length of the rooms; and into this passage external cold air can be admitted to regulate the temperature. The supply of air flows into the rooms horizontally near the ceilings, as shown by the arrows.

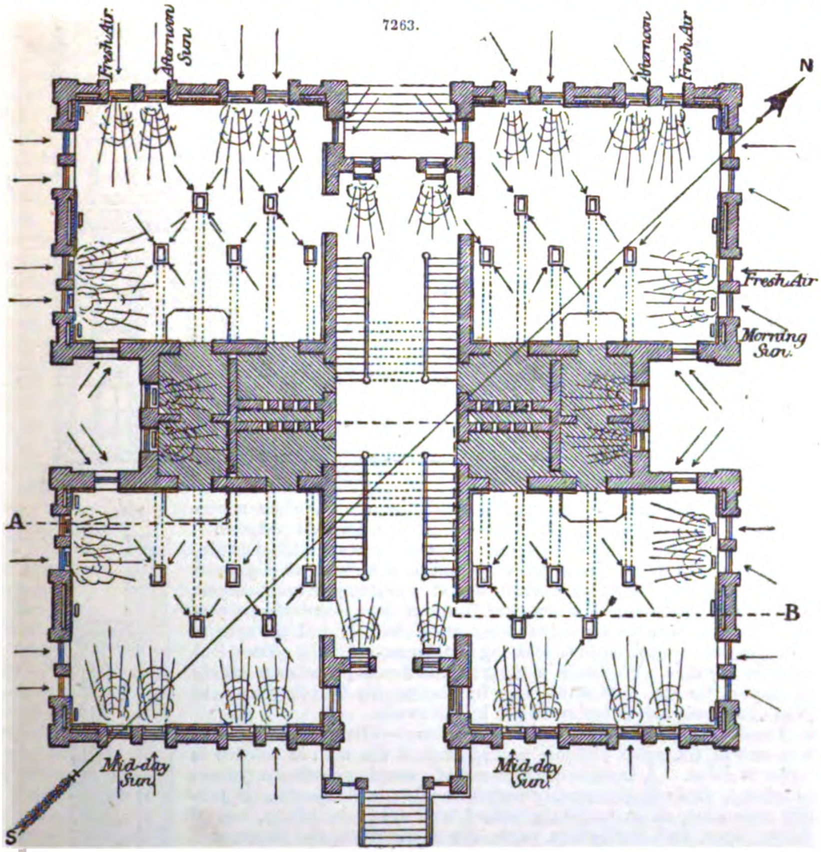
The rooms of the drawing school B are open at night, and offer special difficulties in ventilation, from the large number of gas-burners in use. The plan of abstracting the vitiated air close to the floor cannot be exclusively applied in this case, as it would cause the discomfort of pouring down air of 85° to 95° temperature upon the heads of the occupants. It is necessary, therefore, to allow the heated gases from the combustion of the lights to escape through the openings F in the ceiling, but at the same time, fresh air is made to enter at the sides near the ceiling. In such cases, when

the room has no attics above it through which the outlet openings in the ceilings can discharge, special flues are required to be made for this purpose, and these should be situate, as far as possible, from the points where the admission of fresh air takes place. By means of this plan of ventilation the temperature of the rooms has been maintained till 10 o'clock at night at 71°, at a height of 5 ft. above the floor, and at an average of 75° near the ceiling. But before this plan was adopted, these temperatures were 80° and 91° respectively.

The discharge openings should be made along both of the longer sides of the room, as at G G, Fig. 7261, and they should be as numerous as possible. Their total effective area should be such as to limit the velocity of the air passing through them to 2·3 ft. a second. They communicate with descending passages H, converging below into a main discharge passage K, leading to the bottom of the discharging shaft J. The chimney-pipes I, from the hot-air stove C, are made to pass up this shaft for the purpose of assisting the draught; but a small fire L at the bottom of the shaft is also requisite.

Figs. 7263, 7264, represent a plan and sectional elevation of a block of school buildings, and show a system of ventilation, due to Lewis W. Leeds, of New York, to which the premium was awarded at the Vienna Exhibition. Leeds' system is an attempt to imitate, and where possible to utilize, the means employed in nature to promote a circulation of the air. He observes that the sun, by heating the solid objects upon which his rays fall, causes a gentle and regular circulation of air along the surface of the ground. Reasoning from this fact, he concludes, that in a system of artificial ventilation the immediate object should be to warm the solid substances in a room, the ultimate object of warming the air being then attained in a natural manner by allowing the incoming

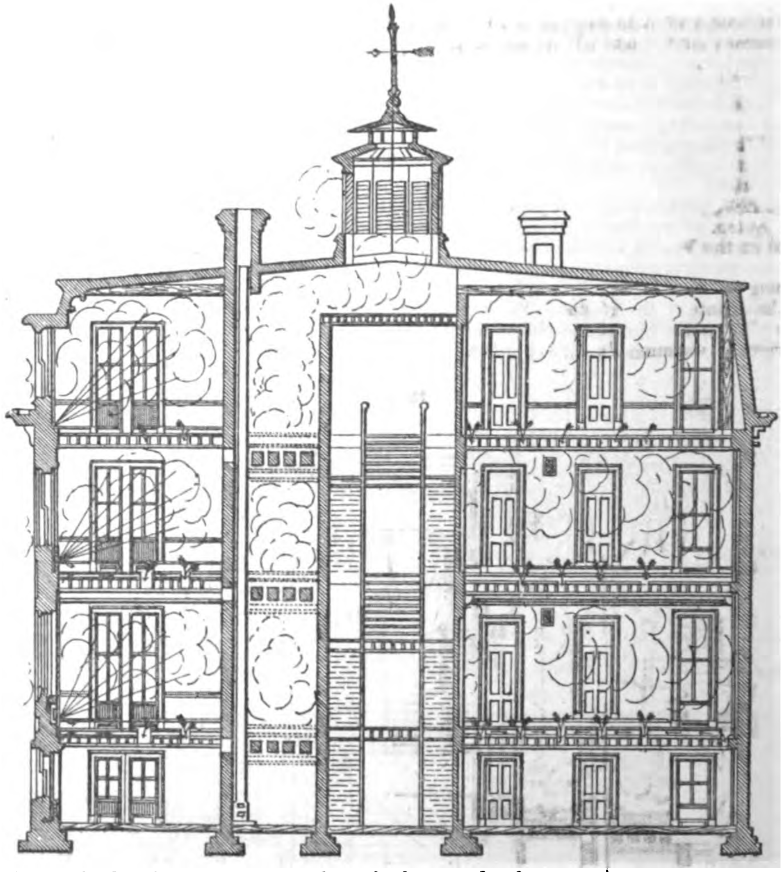
7263.



current to pass over these substances. To carry this conclusion into effect, he proposes to heat the floor and walls of a room, the requisite temperature being that which the summer sun shining on them would produce, that is, from 85° to 90° for the floor, and from 110° to 115° for the walls. To communicate and secure the necessary heat to the floor, Leeds carries off his vitiated air through numerous horizontal ducts running through it, and places at intervals in one of these ducts a steam-pipe, the tops of the joists being well cross-furred. To heat the walls, he constructs a wainscoting of iron, slate, or plaster upon iron laths, and places steam-pipes behind it in the manner shown in Fig. 7265. In addition to this, a steam radiator is placed under each window to correct the excess of cold at that point. Fresh air is admitted through the sill of each window and deflected upwards by the form of the opening. The air thus introduced mingles with the warm air ascending from the radiator, as shown in the drawings, which are exact reproductions, reduced, of the diagrams exhibited

at Vienna in 1873. The means provided for removing the vitiated air are two large up-cast shafts, centrally placed, as shown in the plan. The suction of these shafts is produced by carrying the

7264.



smoke-pipe of the heating apparatus up through them, and, when necessary, by a coil of steam-pipes or a stove placed in them for that purpose.

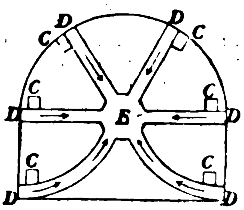
7265.

The advantages claimed for this system of schoolhouse ventilation are, a constant and uniform circulation in every part of the room, avoidance of draughts of cold air, a constant temperature that is practically independent of the opening and shutting of doors, and freedom from overdrying a portion of the air. No doubt these advantages are obtained; but the system does not appear to be applicable to existing buildings, nor to be economical in practice in any case. We ought to observe that Leeds proposes to utilize as much as possible the heat of the sun by placing his building so as to obtain the maximum amount of sunshine in the rooms.

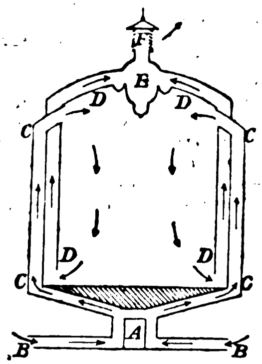
The Ventilation of Theatres and Public Rooms.—The ventilation of a theatre is one of the most difficult problems that the man of science is called upon to solve. A theatre consists not of a single apartment permanently enclosed, like other assembly rooms, or of several apartments permanently separated, as in hospitals, school, and other buildings, but of three large, open, and contiguous parts, the auditorium, the stage, and the corridors, all of which may at one moment be separated one from the other, and the next moment placed in communication one with the other by spacious openings. To this first difficulty must be added the influence of the gaslights, especially those near the roof, the position of the audience placed in rows one above the other, and not horizontally as in other places, and the continual changes that are taking place on the stage and among the audience. These difficulties have long occupied the attention of architects, and many plans have been proposed, some of which have given fairly satisfactory results; but a plan that shall give complete satisfaction has yet to be discovered. A description of the numerous attempts that have been made in this direction would extend beyond the limits of an article like the present; we shall therefore confine ourselves to one or two examples of the most recent practice.

In 1860 a French writer, M. Trélat, in a work entitled Le Théâtre et l'Architecte, proposed a system of ventilation which was a few years later more fully wrought out by Dr. Bonnaford, of the Academy of Science. Subsequently, in 1869, this system was adopted at the New Vaudeville Theatre in Paris. The lighting is by a large chandelier recessed into the ceiling, by which arrangement the space below is kept free from the products of combustion, while the heat of the gas is utilized to draw away the vitiated air. Figs. 7266, 7267, show the circulation of the air in the ventilating flues. A is the furnace placed beneath the floor of the building; B the cold fresh-air ducts; C the warmed fresh-air ducts discharging through the cornices of the stage at the springing of the ceiling, and at the floor of the boxes; D the ducts for the vitiated air which is drawn down behind the boxes and along by the floor of the orchestra, and then made to ascend above the ceiling by means of the suction of the chandelier E, to be discharged at F. In summer, the fresh air is introduced near the top, and admitted through a frieze running all round the ceiling. We have in this system an exact copy of the circulation in the human body; A may be regarded as the stomach in which the combustion takes place; C the arterial blood; D the venous blood; E the heart or motive force, and F the skin, through which the vitiated products are eliminated by means of expiration and perspiration. The system is in exact accordance with the teachings of science, and the experience gained at the Vaudeville showed that with proper attention it would be quite adequate to the requirements of a theatre. In this case, however, it has been in part abandoned, partly because the necessary supervision was not provided to prevent draughts in some portions of the building, and partly, and probably chiefly, because complaints were made that the position of the chandelier was not favourable to the display of the toilettes of the fair portion of the audience.

7267.



7266.



M. Joly, whose authority in matters of ventilation is universally acknowledged, gives it as his opinion that the problem of adequately ventilating a theatre without causing disagreeable and dangerous draughts, though intricate and difficult, is not insoluble; and he proposes means for accomplishing this desirable object, which we will lay before our readers. According to this authority, the difficulties are due mainly to two causes, the powerful suction occasioned by the chandelier, and the communications existing between the corridors and the interior of the building. Hitherto this interior alone has been considered. This is an error that must be avoided. A theatre consists essentially of two concentric envelopes which, for the engineer charged with the ventilation, should constitute but one hall. It may be necessary to point out here some of the defects at present existing.

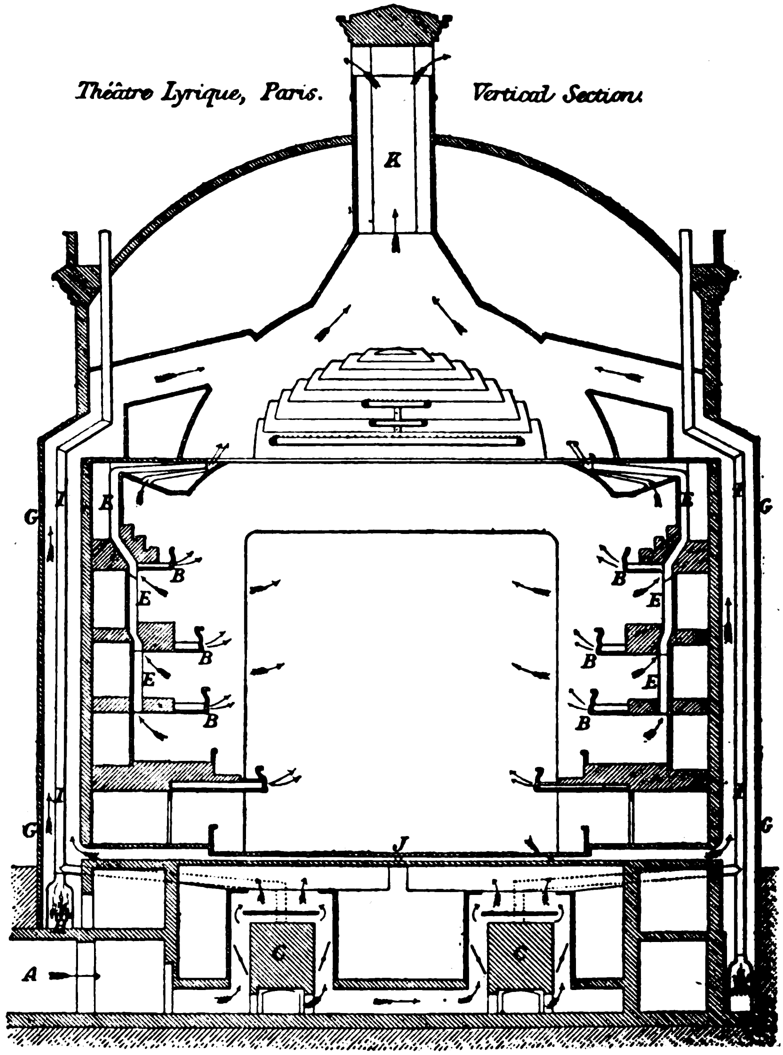
Most persons must have remarked in every theatre a strong up-draught ascending from the stage in the form of a cone, having its apex in the chimney of the chandelier. A material proof of this may be had in pieces containing a banquet scene, as in the Black Domino and Lucretia Borgia, for example. The flame of the candles is seen to be violently agitated and inclined to the orchestra at an angle of 45°. We may conclude *a priori* that this draught, occasioned by a powerful heating apparatus placed at the base of a chimney, produces two effects, which must be counteracted at any cost. It carries the sound waves up to the ceiling, so that the actor's voice can be hardly heard in the front stalls; it occasions a difference of from 10° to 15° between the floor and the ceiling, and consequently a very disagreeable draught every time a door is opened, especially at the bottom, whatever the temperature of the incoming air may be. It may also be remarked that the ventilation caused by the chandelier is of little value; it carries off effectually the products of the combustion of the gas, but its action is hardly felt by the occupants of the boxes, which are open on one side only. Thus, though it produces a brisk current in the middle, that is, the unoccupied space of the theatre, it hardly operates at all upon those portions where the vitiation of the atmosphere is going on. Among the other defects of existing arrangements, may be mentioned a too high and irregular temperature, a vitiated atmosphere, contracted and inconvenient outlets, exposing the audience to great danger in case of fire, disagreeable and dangerous draughts through the boxes when the doors are opened, and an atmosphere in the green-room poisoned by the gas.

The problem of ventilating a theatre consists essentially in maintaining at all times a temperature of about 70° in every part of the building; in furnishing for each person and each gas-burner the requisite quantity of fresh air, after having warmed it in winter and cooled it in summer, and in avoiding draughts, which are always disagreeable and dangerous, especially to the feminine portion of the audience.

To ensure these results, the warm air must, in winter, before the doors are opened, be sent along the floor at once into the portion set apart for the audience, the corridors, and upon the stage. When the public have entered, and not till then, the ventilation will be directed in the manner to be afterwards described; but only through the auditorium and the green-room, the stage, the corridors, and the staircases need only to be warmed. In summer, ventilation is still more necessary than in winter, and the problem has to be solved, without complicating the floors of the lobbies and boxes with interminable ducts, by means which shall improve the acoustic properties of the theatre by diminishing the draught to the chandelier, equalize the temperature from the top to the bottom of the auditorium, and moderate the draughts through the doors. According to M. Joly, the only rational plan of admitting fresh air is through the ceiling, and to this use the cornice lends itself

very effectively, since it is situate far above the heads of the audience, and admits of large openings. The vitiated air is extracted at the points where it is produced, that is, close to the boxes and stalls, and especially near the orchestra and pit-floor, through gratings placed vertically around the pit-boxes. Joly is also of opinion that the auditorium and the corridors, or lobbies, should constitute one single space, as far as ventilation is concerned, and that the circulation of the air through this space should be provided for in accordance with the principle observed in mines, that is, the air is to be introduced at the top, passed through the building, and discharged again at the top. This arrangement alone will ensure equality of temperature, and an efficient ventilation the direction of which shall be favourable to the sound waves. Large openings are indispensable, as it is a well-known fact that draughts are disagreeable in proportion to the narrowness of the aperture through which they pass. To render the above results certain, it is especially necessary, in a theatre, to combine the suction of the furnaces and gaslights, with the action of a mechanical ventilator, producing a slight pressure outwards, and allowing the air to be drawn from any point as required, and to be regulated, warmed, or cooled. This means has been proved by experience to be the most economical when very large spaces have to be ventilated; it is also the most certain means of providing that the incoming current shall be fully equal to the suction, and thereby prevent the ingress of air through the stage and open doors. As accessory means, the suction of the chandelier must be reduced to a minimum by reducing the dimensions of its chimney, so that it may have only such influence on the ventilation as may be deemed desirable. The suction of the gaslights in the

7268.

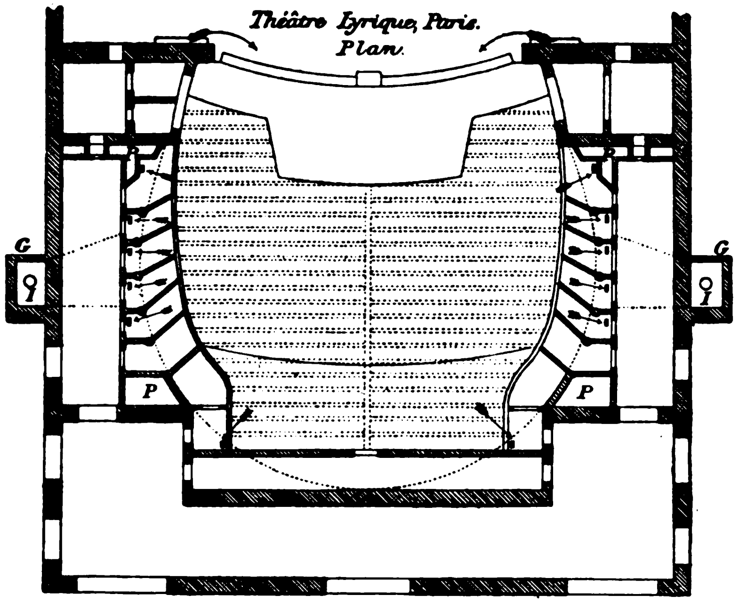


corridors and behind the scenes should also be utilized, and double doors provided in the lobbies and on the staircases. When the air-ducts have been once established, the proper openings for the

regulators determined, and the working of the system thoroughly understood, the management should be placed in the hands of properly-qualified and responsible men, for without this no system however perfect will ever succeed. The proposed solution of the problem may be briefly summed up as follows;—Direct warming of the stage, lobbies, and staircases, and the latter to be furnished with double doors. Moderate warming of the auditorium from the bottom before the public are admitted. On the raising of the curtain, the fresh air, warmed or cooled according to the season, to be admitted through the cornices of the ceiling. Extraction of the vitiated air at the bottom through gratings in risers of the floor and along the pit-boxes. Use of a mechanical ventilator to prevent draughts, especially in summer, and the control of the arrangements placed in properly-qualified hands.

A plan for ventilating a large theatre, proposed by Morin, and adopted at the Théâtre Lyrique in Paris, is shown in the accompanying Figs. 7268, 7269. A description of this plan was given by

7269.



its author in a paper read before the Institute of Mechanical Engineers in 1867, from which we extract the following;—

The number of seats in this theatre is 1470. For the ventilation of the stage and its dependencies, special means have to be applied by an auxiliary discharge flue above the stage, intended for use when required to remove any large quantities of smoke from extensive illuminations. In the body of the house, where the maintenance of a constant ample ventilation is required, there should be a supply of fresh air of 1400 cub. ft. an hour for each person, with the means of increasing this in summer to 2000 cub. ft. an hour. It is important for the supply of fresh air to be obtained from open spaces or gardens, if possible, or else by special shafts bringing the air from a point above the buildings, and far removed from the outlets of vitiated air. In the case of the theatre shown in the drawings, the inlet for fresh air is made in the square of the Tour St. Jacques, by means of a well 11½ ft. diameter, communicating by a tunnel A of the same area with the space underneath the theatre, Fig. 7268, where the warming apparatus and the mixing air-chambers are situated. The velocity of the current in the inlet passage A was ascertained to be 3·08 ft. a second in a special examination that was made some years since, and the sectional area of the passage being 97 sq. ft., the volume of fresh air admitted amounted to 300 cub. ft. a second, which was somewhat in excess of the quantity that the apparatus was designed to supply. This area of inlet, however, has subsequently been allowed to be contracted considerably by the growth of ivy at the entrance.

The admission of the fresh air to the body of the house from the main supply shafts P, P, Fig. 7269, takes place between the floor joists or through the false bottoms made under the floors of each of the rows of boxes and gallery, as shown by the arrows at B, B, Fig. 7268, the air entering horizontally all round the theatre through these spaces, which should not be less than 5 to 6 in. clear height. The fresh air is also admitted by openings from about 10 ft. height in the vertical walls on each side of the stage, and by auxiliary channels under the flooring of the passages, intended specially for extra summer ventilation, and controlled by valves. For preventing the occurrence of unpleasant draughts upon the opening of doors into the exterior passages, these passages have to be warmed to a temperature of about 68°, and inlets of warm air are provided opposite the different doors in the passages.

A portion of the air, on entering by the main inlet passage A, Fig. 7268, is warmed by traversing two sets of heating apparatus C, C, placed in the basement; and the remainder is delivered into mixing chambers for regulating the temperature of the air supplied in the building. The area of

passage through the heating apparatus is 97 sq. ft., and the volume of warm air supplied is 245 cub. ft. a second, giving a velocity of current of 2·5 ft. a second.

The vitiated air is taken off through numerous openings in the lower part of the sides of the boxes and passages, and in the risers of the steps in the gallery, each box or pair of boxes having a separate discharging flue; and the total area of these openings has to be such as to allow the velocity of the air not to exceed 2·3 to 2·6 ft. a second. The exhausting flues E, E, from the several tiers of boxes are made to rise towards the dome F above the chandelier, while those from the pit, orchestra, and boxes on the ground tier, are carried below the floor into main flues leading to the vertical shafts G, G; and the area of these exhausting passages should be such as to give a velocity of current of 3·3 to 3·9 ft. a second. In the pit and orchestra, outlet gratings should be placed all round the sides, and in the sides of the air-passages underneath the seats; these outlets open into the space left under the floor, which leads to the main exhausting shaft G on each side, this space being divided accordingly into two portions by the central partition J. The outlet gratings should not be placed in any case in the floor, as was done in this theatre, contrary to Morin's intention.

The cast-iron chimney-pipes I, I, from the heating apparatus are carried up the exhausting shafts G to aid the draught, the pipes being kept isolated throughout; and a small fire-grate H is placed at the bottom of each shaft, for use when extra ventilation is required in summer. The area of the exhausting shafts G, G, is required to be such as to give a velocity of current of 5·6 to 5·9 ft. a second; and they should lead, when possible, to the dome over the centre of the theatre, into which all the outlet flues from the upper tiers of boxes also discharge. The general outlet shaft K above this dome should be built of brick, not metal, and should be carried at least 20 or 25 ft. above the top, its area being such as to give a velocity of current of about 6·6 ft. a second.

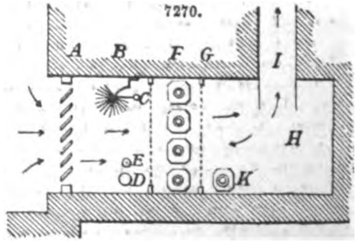
A series of experiments on the ventilation were made on five successive nights in May, 1863, with the external temperature ranging between 56° and 74°; and the result obtained was that with an average consumption of 4 cwt. of coal a night, the removal of 166 cub. ft. of air a second was effected, amounting to 1400 cub. ft. an hour for each seat of the pit and orchestra. With this ventilation the temperature of the house can be maintained within comfortable limits; but this extent of ventilation is not actually employed, as the intended use of the two large exhausting shafts G, G, is not carried out. The experiments made at the same time on the ventilation of the boxes showed that an abstraction of 377 cub. ft. of air a second was effected by the centre shaft over the dome, amounting to 1800 cub. ft. an hour for each seat. The actual average ventilation for the whole house during the five evenings was found to be 1330 cub. ft. an hour for each seat. By this uniform ventilation the temperature in the different rows of seats was maintained most remarkably constant, the average temperatures in the first and fourth tiers being 68° and 70° respectively, when the external temperature was 52°; and when the latter was 70°, their temperatures were 78° and 80° respectively; in other large theatres, however, which are not so ventilated, these temperatures are not unfrequently as high as 95° to 105°.

At another trial in November, 1863, when the external temperature was as low as 39°, the temperatures within the house were found to be maintained at 66° on the stage, 71° in the orchestra stalls, 73° in the boxes, 74° in the gallery.

The ventilation of the Houses of Parliament at Westminster offers a good example of a system suitable to buildings of that character. Probably in no instance have the general arrangements and the details been carried out with such strict regard to the object proposed as in the case of these buildings. Every existing system was examined, every authority consulted, numerous experiments were made, and no expense was spared, to obtain a perfect plan of ventilation. We may therefore regard the one finally adopted as the embodiment of all that was at that time known concerning the subject. Moreover, it is under the constant supervision of competent persons, and is on that account valuable as an illustration of what may be effected by such means.

The heating apparatus, consisting of immense steam-boilers, is placed beneath the central hall. Steam was chosen as being more prompt in its action than water, and so enabling the temperature in a given place to be changed in a shorter time. The number of members present is continually varying, and it is therefore important that the temperature and the ventilation should be under immediate control. To regulate these in accordance with the necessities of the moment, telegraphic communication is established between the Speaker and the person in charge. The mode of lighting differs in the two chambers, but the warming is carried out in the same way in both. Fig. 7270 shows a portion of the arrangement adopted. The fresh air is admitted on the side of the river through louvres A, the opening of which may be regulated in a chamber B. In this chamber, according to the seasons and requirements of the moment, the air passes between jets of cold water thrown out as spray from a tube C. If it be desired to increase the moisture of the air without cooling it, a divided jet is let fall from the pipe E, which jet is vaporized by the steam-pipe D placed beneath. In the next chamber, F, are the heating apparatus proper. These are Gurney's steam-batteries, formed of plates of metal 1 ft. in diameter, arranged around a steam-pipe at a distance of ⅜ in. apart. Their number, that is, the extent of surface, is calculated according to the volume

7270.



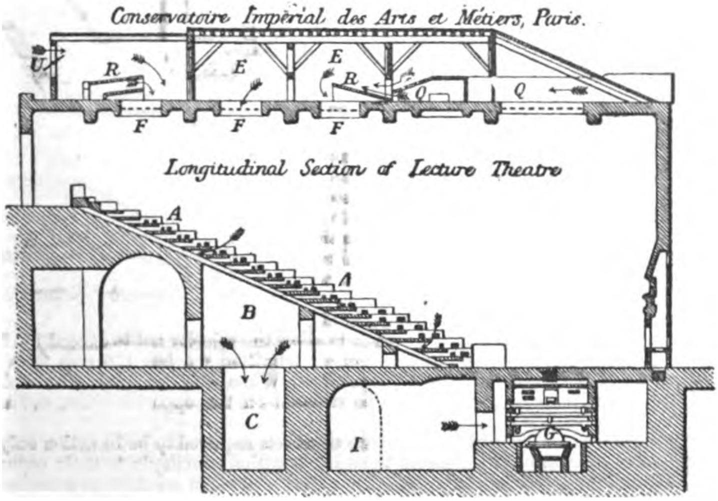
of air to be heated. From thence the air is passed through a gauze veil, to intercept the dust and soot from the atmosphere. From the large chamber H it ascends through circular ducts I, and is distributed over the assembly chamber, into which it is admitted through gratings in the floor covered with matting. At the bottom of the duct I are fixed brattice-cloths, which, when the current is too strong, are raised so as temporarily to partially close the entrance. To modify the

temperature, according as the House is empty or suddenly filled by a rush of members when an important question is brought forward, in the chamber H additional batteries K are placed, which are brought into or taken out of use in obedience to orders received from the Speaker.

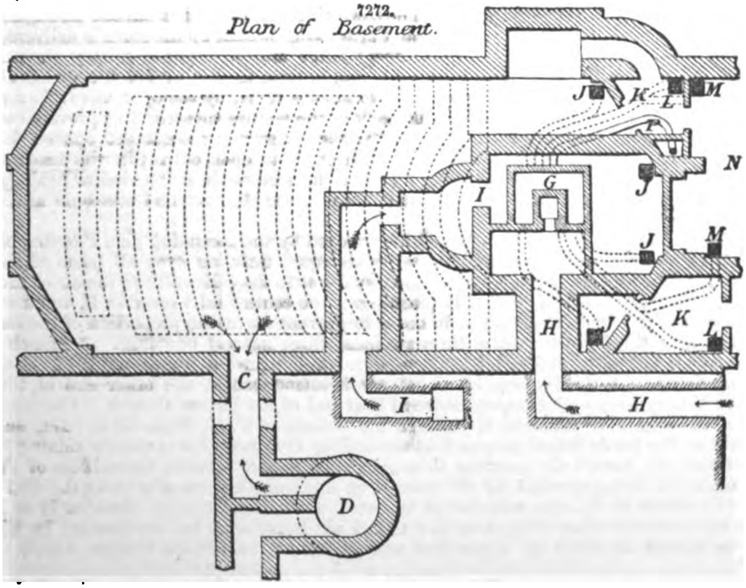
The vitiated air is extracted through the panels of the ceiling by the suction of a large furnace situate at the base of a chimney. As the ordinary means of regulating this draught flue, and protecting it from the influence of the wind, would have had a bad effect on the appearance of the building, the smoke pipes are enclosed in iron turrets, designed in the style of the rest of the structure. The gaslights, which in both Houses are in the ceiling, though differently arranged, assist the draught of the flue in extracting the vitiated air.

An excellent plan of ventilating a large meeting room is shown in Figs. 7271 to 7274, which represent the lecture theatre of the Conservatoire des Arts et Métiers at Paris. In this case, as in the Théâtre Lyrique, the arrangements were designed by General Morin, and carried out under his supervision. These arrangements are also described by Morin in the paper previously alluded to.

7271.



7272.

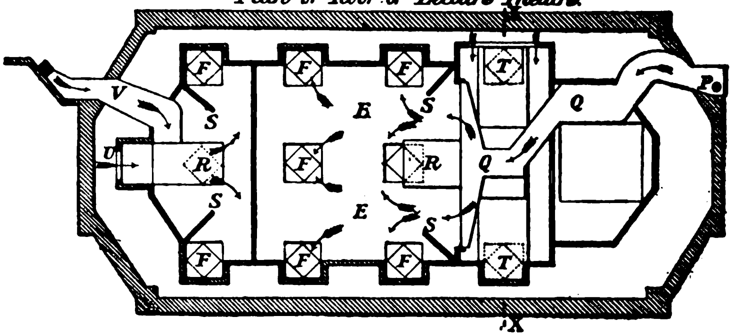


The vitiated air is taken off through a large number of orifices made in the risers of the steps A, A, Fig. 7271, opening into the passage B below the seats, which space communicates by an outlet passage C, Fig. 7272, with the discharging shaft D. The requisite draught is maintained in the shaft D by means of a fire at the bottom, dampers being placed in the passage C to moderate the current

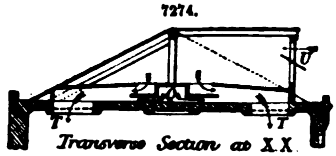
of the air. The supply of fresh air is introduced from a mixing chamber E in the roof, and admitted to the lecture theatre through openings F, F, distributed over the surface of the ceiling.

7273.

Conservatoire Impérial des Arts et Métiers, Paris.
Plan of Roof of Lecture Theatre.



7274.



Transverse Section at X X.

In such buildings the area of openings for the abstraction of the vitiated air should be sufficient to prevent its velocity through the openings exceeding 2·3 to 2·6 ft. a second, the openings being distributed as uniformly as possible over the whole of the steps A, A. The velocity of the air in the outlet passage C should not exceed 3·9 ft. a second; and the velocity in the discharging shaft D should amount to 6·6 ft. a second, in order to ensure the stability of the current.

The inlet openings F, F, for supply of fresh air, when situated in the ceiling should have such an area as to allow the velocity not to exceed 1·6 ft. a second; in this lecture theatre, where the total quantity of air admitted reaches 170 cub. ft. a second, the area of openings slightly exceeds the above proportion. When it is requisite in such places for the inlet openings to be at the sides, they should be situated on two opposite sides, and as high from the floor as practicable.

As the ventilation of buildings like this lecture theatre is required to be in action only when they are occupied, whilst the warming is needed to be in operation previously to their occupation, it is necessary to have the means of warming them by special orifices, in addition to those which supply the ventilation. For the purpose of warming, the large hot-air stove G is employed, Fig. 7272, situated under the lower end of the room; and the air necessary for combustion is supplied to it from the basement through the passage H. The fresh air to be heated is admitted through a separate passage I from the open courtyard adjoining, and after being heated by the stove is delivered into the room through the four openings J, J, in the floor; these are only opened during the preparatory warming of the lecture theatre while it is empty, and as soon as it is occupied they are closed. A constant supply of hot air is maintained to the two lobbies K, K, by the openings L, L, and also by the openings M, M, to the laboratory N at the back of the lecture theatre; this prevents any objectionable draughts of cold air occurring whenever the intervening doors are opened during the occupation of the theatre; and the doors being all made to open outwards, the tendency of the entering air is to close them. At the upper end of the lecture theatre a similar heating stove is provided, but of smaller size, for warming the main entrance staircase and vestibule at that end of the room.

A portion of the hot air from the stove G is conveyed by the ascending pipe P to the mixing air-chamber E in the roof; and in order to ensure its equal diffusion over all parts of the lecture theatre, the mouth of the hot-air passage Q is widened out to the full width of the air-chamber E, as in the plan, Fig. 7273; while a hood R is placed over the central inlet opening F, and screens S, S, are interposed at the two side openings, in order to prevent an undue proportion of the fresh warm air from entering the lecture theatre through these three nearest openings. A branch from the hot-air passage Q to the two side openings T, T, Fig. 7273, ensures a proper supply of hot air to each of these openings. A similar supply of hot air is introduced at the other end of the roof by the passage V from the smaller heating stove at that end of the lecture theatre. The fresh cold air is admitted into the roof chamber E through the entrances U, U, Figs. 7271, 7274, and by the arrangement of the hoods R and screens S at the ceiling apertures, the thorough mixing is ensured of the cold and the heated air previous to entering the lecture theatre, the orifices of the hot-air passages Q and V being situated in all cases close underneath those admitting the cold air. By means of the valves U, U, the entrance of the cold air to the mixing chamber E is regulated according to the temperature desired in the mixed air introduced for ventilation; in winter this temperature should be about 3½° below that maintained in the lecture theatre, which should be about 68°.

The Ventilation of Club-houses.—The conditions imposed by the arrangements of club-houses, which are composed of several apartments, sometimes connected, sometimes isolated, vary so greatly, that no system can be applicable to any two buildings without considerable modifications. These institutions possess, however, several features in common which must be considered in devising a suitable plan of ventilation. The apartments are large and lofty, and thus offer great facilities for

the introduction of the fresh air without causing unpleasant draughts; they are also provided with a large number of gas-burners, and at certain times of the day they are well filled with occupants. The atmosphere of the dining-rooms is laden with the odours of the viands, and that of the smoking-rooms with the fumes of tobacco. It is obvious that to keep the atmosphere of these rooms in a fit state of purity, large volumes of fresh air must be admitted. This will necessitate spacious air-ducts, and a correspondingly powerful suction or propulsion. Mechanical ventilators have been applied to this class of buildings with very satisfactory results. The Reform Club-house in London offers a very good example of this mode of ventilation; and as the general plan is well designed, and the details carefully carried out, it may be considered as one of the best of its kind.

The fresh air is supplied by a fan capable of throwing 11,000 cub. ft. of air a minute. This fan, which is driven by a steam-engine of 5 horse-power, is placed in a vault in front of the building, and it throws the air into a spacious tunnel under the basement story of the building. The steam of condensation is utilized to warm the incoming air, the heat being communicated by the steam to three cast-iron chests of a cubical form. Each of these chests measures 3 ft. externally, and is divided internally into seven parallel cases, each 3 in. wide, which are separated by alternate passages of the same width. The fresh air from the fan passes through these passages, where it is heated to a temperature of about 80°, into a bricked chamber in the basement. From this chamber it is conveyed by separate ducts, provided with registers, to the several apartments of the building. The vitiated air is carried off through pipes into a brick chimney, the suction of which is assisted by a stove placed in the top story, and discharging its smoke into it. The economy of the arrangement is shown by the fact that 2 cwt. of coal is sufficient to work the engine for twelve hours, the power of the engine being besides available for pumping water for purposes of the establishment, and raising coals to the several apartments on the upper stories.

The Ventilation of Dwelling-houses.—The ventilation of dwellings is a question of really vital importance, involving as it does the health of every member of the community. And yet, strange as it may seem, nothing in the construction of houses is so little thought of. No expense is spared in ornamental details; every care is taken to provide an abundant supply of light and water; judgment is exercised in the choice of a site that shall be at once cheerful and wholesome; but that which is of still greater importance, namely, the removal of the vitiated air from the rooms, and the supply of pure air in a way that shall be neither disagreeable or dangerous, is either not thought of at all, or the cost is grudgingly allowed. This question of house ventilation is of special importance to the females of a community, since nearly the whole of their lives is passed within doors. But to any thinking person the gravity of the subject is obvious, and need not therefore be enlarged upon.

It is seldom that a complete system of ventilation is applied to a dwelling-house, even when the ventilation is provided for. Usually in each room there is an opening communicating with the outer air, either directly or through a duct, in the length of which means are provided for warming the passing current, and the fresh air admitted through this opening is left to escape through the chimney. This system, if it deserve the name of system, is both pernicious and inefficient. It occasions unpleasant draughts, and under the most favourable conditions it promotes an unequal circulation. But if we consider that for several months in the year there is no fire in the room to produce the requisite suction, and that frequently in the bed-rooms a fire is never lit, we shall at once see that any system of ventilation by single rooms must necessarily be totally inadequate to the requirements of a dwelling. An efficient system will therefore embrace the whole house, and only such is worthy of consideration. It has been urged that the difficulties attending such a system are too great to render its adoption practicable. Prejudice against novelty lies, however, at the root of this objection. That the difficulties are more apparent than real is proved by the success which has attended the introduction of a complete system in certain instances, some of which systems we propose to describe.

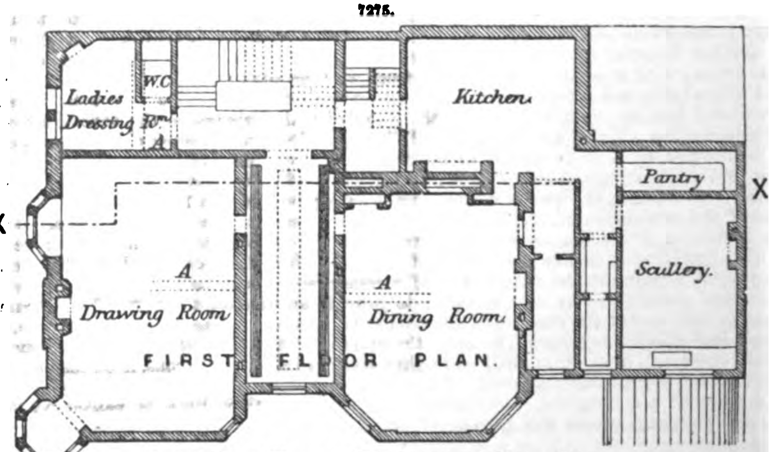
One of the most simple and efficient is that due to Drs. Drysdale and Hayward. These gentlemen provide an up-cast shaft to carry off the vitiated air from the whole house, and employ the waste heat of the kitchen fire to produce the requisite suction. The advantages of this are that the suction is kept in constant operation without the attention of any person in charge, and the cost of producing it is nil. The air is warmed before being admitted, and the apertures both for admission and extraction are near the ceiling. A central hall is provided, into which the warmed fresh air is conveyed. The air-ducts for each room draw their supply from this central hall, into which all the rooms open. By this means a cold draught is prevented when the doors are opened. The vitiated air escapes through a zinc pipe in or near the ceiling, and is conveyed by flues in the wall up to a foul-air chamber under the roof. This foul-air chamber consists of a zinc drum 6 ft. in diameter by 5 ft. high, into which the foul-air flues open at the same level. A discharge pipe, so placed as to draw equally from all the flues, leads from this chamber down to below the kitchen fire-place, and up behind the fire to the up-cast in the kitchen chimney-stack. The authors of this plan of ventilation have fully explained their views in a valuable little work entitled Health in Comfort in House Building, from which we extract the following description of a dwelling-house constructed by them in accordance with their system.

"The house, plans and section of which are shown in Figs. 7275 to 7277, consists of basement, ground floor, and first, second, and third floors. The basement is devoted principally to the collecting and warming of the fresh air. On the ground floor are the cellars, a ball-room, two professional rooms, a gentlemen's cloak-room and water-closets, and the main entrance, with vestibule and stairs' lobby, and servants' entrance and lobby. The first floor is the living-floor. On this is a drawing-room, with ladies' dressing-room and water-closet; a dining-room, with china closet; and a kitchen, with cook's pantry, larder, scullery, and butler's pantry. The second floor consists of the family bed-rooms, four in number, with breakfast-room, housemaid's closet, bath-room, and water-closet; and the third floor, of the servants' bed-rooms, also four in number, with children's play-room, store-room, and two water-cistern rooms. Above this, beneath the ridge of the roof, is the

foul-air chamber F, into which the vitiated air of all the rooms of the house is collected, and from which it is drawn by the kitchen fire by means of a down-cast C, passing down to the ground floor, and then ascending behind the kitchen fire D, and up the chimney round the smoke-flue.

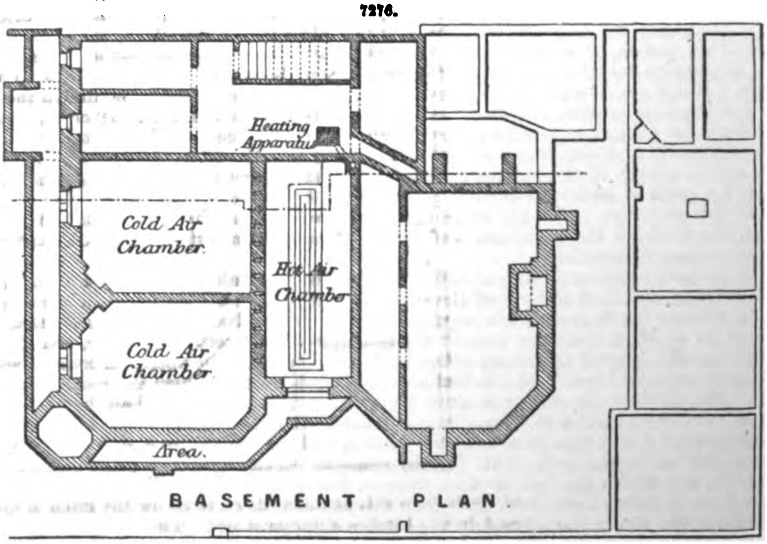
"The principal part of the house consists of a front and back block, each about 33 ft. by 20 ft., with a lobby 9 ft. wide between them, running north and south. This central lobby is the warmed air corridor, or ventilating lobby; it is lighted by a window at its south end by day, and by Ricketa's globes by night. At its north end it is shut off from the main staircase, vestibule, and front entrance by vestibule doors. Out of this lobby open all the principal rooms of the house. The front entrance, with the vestibule and main staircase, 12 ft. wide, are placed, not in the centre, but at the north end of the house. The main staircase runs between the vestibule in front and the kitchen stairs behind, and is lighted by a skylight. The servants' entrance and lobby are from the south,

7275.



A.A.A. Zinc Flues in Thickness of Floor above

7276.



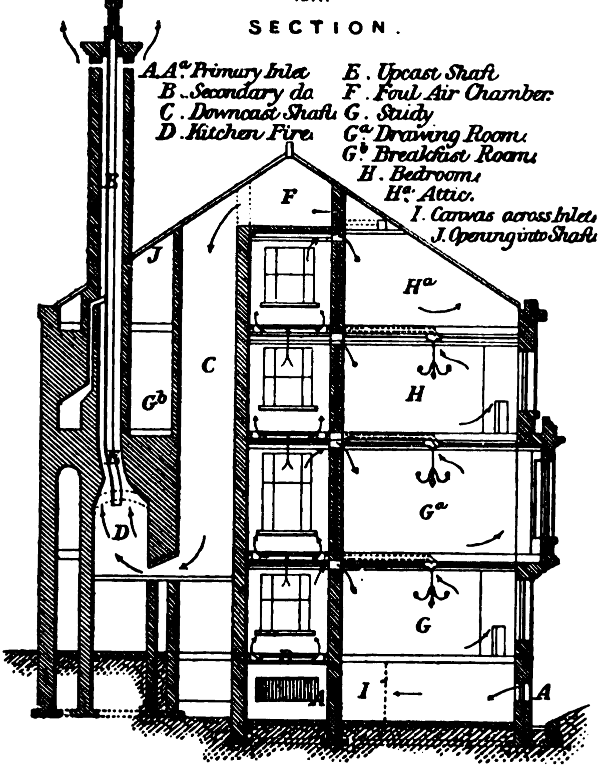
behind the ventilating lobby, and the servants' stairs run up between the main staircase in front and the kitchen behind. By this arrangement there is an easy approach from the kitchen to the dining and drawing rooms, and to both the front and the side door; and the lobby into which opens the door that lets in the cold air by being frequently opened, is shut off from that out of which the living-rooms open, which could not be if the entrance were in the middle of the front.

"The central corridor is an essential part of the house. It serves, of course, as lobbies to the rooms on each floor; on the ground floor it serves also as a museum, and between the dining and drawing rooms it serves as a bagatelle-room and picture-gallery; and by the introduction of gratings into the ceiling and floor of each story, it also serves as an open corridor from basement to attics.

"Along the centre of the ceiling of each story of the central corridor is an ornamental lattice-work, 2 ft. wide, and along each side of the floor above is an iron grating 1 ft. wide. These allow the warmed air to ascend from the lobby beneath to the lobby above; but the floors check it for the

supply of each story, and prevent it from rising directly to the top one, as it would in a stairs' lobby.

7277.



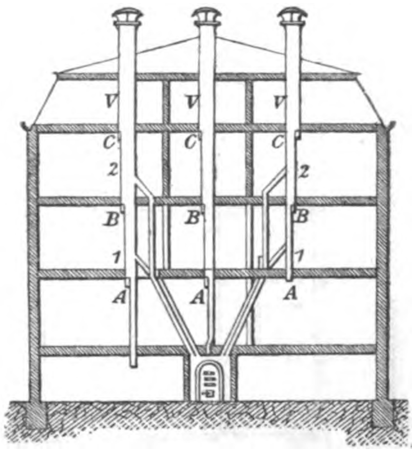
"The incoming air is warmed by a hot-water apparatus fixed in the basement of the stairs' lobby. The flow-pipe is carried up, and run one length of the bed-room lobby; it is then brought down, and run once along the picture-gallery, after which it is brought down to beneath the secondary inlet B, or the opening in the ceiling of the basement of the central lobby, which it covers, running backwards and forwards the whole length ten times; the fresh air enters into the lower part of this basement, and, rising, is warmed by the heated pipes; it then passes through into the lobby of the ground floor, and thence into the lobbies of the first, second and third floors, so that the central corridor is filled from the ground floor to the attics with warmed fresh air. Above the attic floor, this corridor is continued to the slates, and made into an air-tight chamber under the ridge of the roof, to receive the outlets of the vitiated-air flues from the different rooms of the house. Out of this central corridor all the principal rooms open, and out of it they receive their supply of fresh air. The cornice round the ceiling of this corridor, and that of each of the rooms opening out of it, has a lattice central enrichment 7 in. deep, and the wall between these two cornices is perforated by as many 7 in. by 5 in. openings as the joists will allow, so that the fresh air has a free passage from the corridor into the rooms, even when the doors are shut. The drawing-room has nineteen of these openings, affording an inlet of fresh air of more than 4½ sq. ft. distributed along the whole length of the wall on the side of the room opposite the fire-place. The dining-room has fifteen openings, affording an inlet of considerably over 3½ ft. Over the gaselier in the centre of the ceiling of each room is a perforated ornament covering an opening 9 in. square into a zinc tube, A A in the plan, 9 in. by 4½ in., affording an outlet for the vitiated air of 40 sq. in. This zinc tube goes along between the joists of the ceiling into a flue of the same dimensions in the thickness of the wall, between the corridor and the room above, where it is provided with a regulating valve. This flue discharges into the foul-air chamber; there is a similar flue from the cloak-room, dressing-room, breakfast-room, bath-room, kitchen, the hall-lamp, and from all the water-closets. All of these flues open separately into the foul-air chamber. Out of the north end of this chamber goes a brick flue or shaft, the down-cast C taken from the back staircase. This down-cast outlet shaft goes straight down to below the first floor, and then crosses eastward and rises up behind the kitchen fire-place, where it is flat, 6 ft. by 1 ft.; it is then collected into a nearly square shaft, 32 in. by 26 in. Up the centre of this shaft runs a circular earthenware smoke-flue from the kitchen fire, 18¼ in. outside diameter, leaving a foul-air shaft, the up-cast, surrounding the smoke-flue. These together form a large chimney-stack, which is carried up to a greater height than any other chimney of the house."

This system is a truly scientific and rational one. It is extremely simple and economical; it is continuous in its action, and operates by night as well as by day, in summer and in winter, and it does not require any attention. No doubt such a system is beyond the reach of many; but it might be modified to suit less favourable conditions than those to which its authors were subjected. It shows at least that a perfect ventilation, combined with a proper warming of the atmosphere of a room, is not an impossibility.

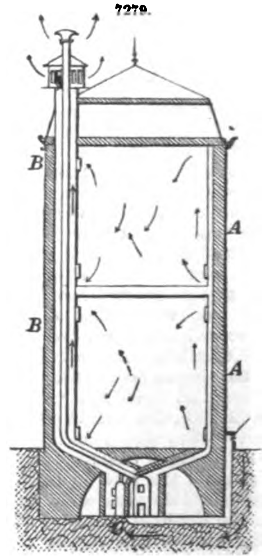
Another mode of ventilating a whole house by a single apparatus, due to Dr. Griscom, of New York, is shown in Fig. 7278. It consists in utilizing the smoke-flue of the heating apparatus to produce the suction necessary to draw away the vitiated air through supplementary flues contiguous to the heated-air flues. As represented in the figure, each hot-air flue enters at the bottom of the room, at the points 1 and 2, for instance; while, for the escape of the vitiated air, openings regulatable by a sliding cover, are provided near the ceilings, as A, B, C; suction through these openings being produced by the column of hot air in the flues which run up to the ventilator V in the roof, and increase in size at each story. If single flues are employed to renew the air of a room, the air which they contain may be colder or heavier than that of the room, and consequently may

produce an effect contrary to that desired. The advantages of Dr. Griscom's system are, that it provides at all times an efficient suction, is independent for every room in the house, operates during the night by the accumulated heat of the apparatus, and acts in summer by merely opening only those openings which are provided for the extraction of the vitiated air. This system, either in its complete or in a modified form, has been much employed in America, and is very generally applicable.

7278.



7279.



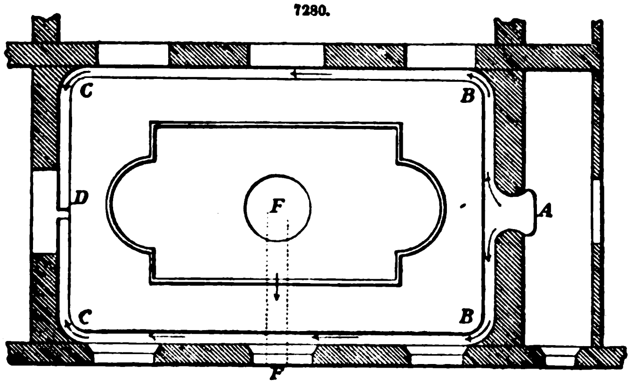
A third method of ventilation, described by Joly, is represented in Fig. 7279. This method, which may be adopted with advantage in certain cases where the form of the building will admit of the flues being arranged in the manner shown in the figure, consists in employing the heating apparatus both in summer and in winter for the supply of fresh air. In winter the heated air will be admitted through the lateral openings A, and the vitiated air extracted through the openings B, or up the chimney of the apartment, if it have a fire in it. In summer the fresh air is admitted through the same openings A, and extracted through the openings B by the suction of a special heating apparatus placed in the basement at C. When several stories have to be ventilated, provision must be made by registers and valves that the vitiated air from one story do not escape into the next. This system may be modified in numerous ways to suit the conditions of a given case. The same may, indeed, be said of all the systems we have described. It would be beyond the scope of an article like the present to point out the various modifications that each is susceptible of, even if it were possible to do so. These modifications are as numerous as the circumstances that may arise, and they must be left to the knowledge and skill of the person to whom the design is entrusted.

In large mansions the ventilation of the reception-room demands special attention. Here, at certain times, especially when used as a ball-room, a large number of persons are assembled, whose bodies, aided by the numerous gas-jets, heat and vitiate the atmosphere in an unusual degree. The ventilation arrangements in these apartments should therefore be capable of admitting large volumes of fresh air. But a grave difficulty in these arrangements arises from the heated state of the persons present, and especially from the character of the ladies' dress, which render it necessary to admit the air with a very low velocity, as draughts in such circumstances are in the highest degree dangerous. Thus a primary condition in the ventilation of such rooms is that the apertures of admission should afford a large area for the incoming current. It is also indispensable that these apertures should be widely distributed, and situate as far as possible from the occupants of the room. The warming of the fresh air previous to admission is, in these cases, a matter of the highest importance. It is, indeed, an obvious fact that the passage of large volumes of cold air through the room at such times would cause great discomfort and serious danger. To prevent this, in spite of the continual opening and shutting of the doors, is a problem extremely difficult of solution. The plan of a central corridor, arranged as in Drs. Drysdale and Hayward's system, would meet the exigencies of the case best, but architectural and other reasons will frequently render the adoption of such a plan impossible.

When, as is often the case, neither the floor nor the ceiling is available for the purpose, the fresh air must be introduced either through pilasters against the walls, having the aperture directed towards the ceiling, or through the cornices provided with numerous openings turned in the same direction. A plan of ventilating such rooms, adapted by Joly to several Parisian *salons*, is represented in Fig. 7280. The fresh-air duct enters from an adjoining room A, or it may be from a lower story; after traversing the wall, it is divided into two portions, which run in opposite directions, as B, C, D. Were the inlet not arranged in this manner, the whole of the air would enter at A, and cause a draught at that part without ventilating every part of the room. The vitiated air is

extracted through perforated openings on the opposite side of the room by means of the suction of a furnace or a mechanical ventilator. Two thermometers, one placed in the fresh-air duct, and the

7280.



other in the foul-air duct, should be employed to show the temperature of the air as it enters and as it issues. The vitiated air may also be extracted through the smoke-flue of the fire-place by means of a portable stove, or, better still, by jets of gas in the flue, fixed specially for reception days. In such cases the air must be allowed free access to the chimney, all obstructions, such as are frequently used as ornament, being removed out of the way. To carry away the hot vitiated air from the gaselier, a flue F F is provided, which runs along between two joists in the floor above, and discharges into a chimney.

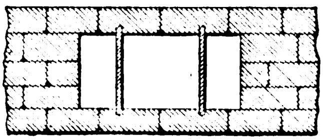
The systems we have described can be applied in their entirety to houses only at the time of their erection. Sometimes one of them may, with considerable modification, be adapted to an existing building; but usually the plan of ventilation which the exigencies of a building, constructed without any regard to such sanitary arrangements, necessitate, is merely a palliative one. Frequently little more can be done than to provide openings for the admission of fresh air in the upper framing of windows and doors. Such openings should always be directed towards the ceiling, for the purpose of distributing the air and avoiding draughts, and they should be furnished with a slide to regulate the incoming current. If means be provided for warming the air that enters over the door, these openings should alone be used in winter. With such an arrangement, the system of ventilation may be a fairly efficient one, and in many cases a little skill only is needed to contrive it. It is best to warm the air of the hall or passage from which the fresh air is admitted, because the discomfort of suddenly letting into the room large volumes of cold air by opening the door is thereby avoided. But when this is not practicable, warm air may sometimes be brought to the inlet aperture by means of a pipe. To allow the vitiated air to escape freely, the chimneys should be kept open when there is no fire, and, whenever possible, outlets should be provided in the ceiling or in the angles of the cornices. If these outlets can be placed in communication with the kitchen chimney, the efficiency of the ventilation will be greatly increased.

The ventilation of the bed-rooms presents the greatest difficulty, and is perhaps the most important. During the day-time, when the rooms are empty, the suction of the smoke-flues from the rooms beneath produces an active circulation; but at night, when the rooms are occupied, the fires below being extinguished, the circulation ceases. This happens even where a fairly complete system of ventilation is carried out, and the foul-air flues are in communication with the smoke-flue of a special heating apparatus, because the fires cannot be attended to at night. The consequence is that the atmosphere of sleeping apartments gets into a highly vitiated state. This can be readily detected by the smell which, from the above-mentioned causes, is peculiar to bed-rooms. There is no doubt but that serious injury to health, especially with children, is occasioned by this absence of ventilation at night. It would conduce to economy by avoiding sickness to keep a fire burning the greater part of the night for the sole purpose of promoting a circulation of air in the bed-rooms. For this purpose coke might be employed, which is cheap, and will burn for a long time without attention. In towns, where gas is available, a burner placed so as to be capable of being turned up the chimney will effect all that is desired.

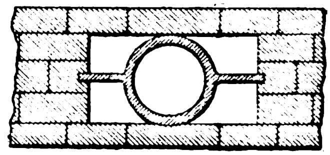
In every system applied to dwelling-houses, summer ventilation should be provided for. During five months in the year the sitting-rooms are without a fire in them, and consequently the suction of the smoke-flues is not in operation. If this alone be relied on to produce a circulation of air, we shall have stagnation during a large portion of the year, and at that season when it is most likely to cause the greatest injury to health. It is true that during the hot weather the windows and doors are freely opened. But they are not left open all the day, and in dull, wet weather, whatever the season may be, they are kept tightly closed. To remedy this defect, the vitiated-air ducts should, whenever possible, be made to communicate with the kitchen chimney, in which there is a fire at all times. At the time of the erection of a building there will be little difficulty in carrying out such an arrangement, and very frequently, in the case of existing houses, it may be readily applied by making use of iron pipes fixed in convenient situations. Water-closets, wash-houses, and the kitchen itself, should always be ventilated by the kitchen fire, since for these offices a constant and vigorous suction is indispensable. The situation and construction of the kitchen chimney are thus matters of considerable importance. The vitiated air should not be extracted through the smoke-flue, not even from the kitchen itself; but there should be special flues provided, heated by

the smoke-flue. When there is but one air-flue, it may surround the smoke-flue in the manner described in treating of the ventilation of St. Thomas's Hospital; but it is better to provide several flues, one of which should be devoted exclusively to the ventilation of the water-closets, and another to the ventilation of the kitchen. These flues may be constructed in several ways; Fig. 7281 shows one arrangement giving two air-flues, and Fig. 7282 another by which four are obtained. If the

7281.



7282.

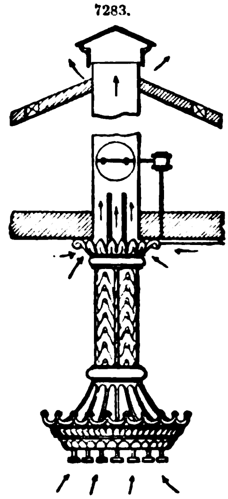


vitiated-air ducts from the different rooms in the house be placed in communication with these flues, it is evident that an adequate ventilation will be maintained at all times without the cost of special fires. We cannot too strongly insist on the necessity of putting all the water-closets in communication with one of these flues, which, as we have already said, should be used exclusively for that purpose. Only by such a provision can the dangerous effluvia from these places be completely and certainly removed. It is important that the kitchen chimney-stack with the foul-air flues should be carried up to a greater height than the other chimneys of the house, as otherwise the down-draughts through the latter in summer might carry the foul air back into the rooms.

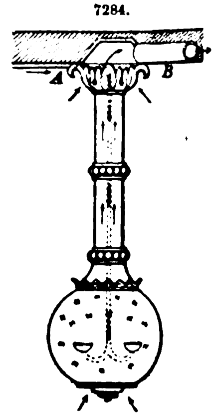
In ventilating a kitchen, more perhaps than any other apartment, it is necessary to provide an abundant supply of fresh air previously warmed by being passed behind the fire-place. If the air be admitted cold, the servants will certainly close the apertures, and so destroy the ventilation. The closing of the inlet apertures may even change the up-cast foul-air flue into a down-cast when the fire is very active, a circumstance that would cause the contents of all the other flues to descend into the kitchen. For the admission of the fresh air in summer, openings over the windows provided with a sliding cover will be sufficient.

There remains another means of extracting the vitiated air from an apartment that we have not yet noticed. The combustion of gas heats and vitiates the atmosphere of a room in a high degree, and it has been found necessary to provide an immediate means of exit for the burned air. As the gas-burner is, in most cases, pendent from the ceiling, the opening for this purpose is made in the centre of the ceiling directly over the burner. This opening is in communication with a passage or flue, which conveys the products of combustion into the external atmosphere. It is obvious that this flue may be made available for the discharge of the whole of the vitiated air from the apartment, and such in fact is frequently done. In London especially, entrance-halls, shops, eating-houses, clubs, reading-rooms, and public buildings, are lighted by a form of gas-burner known as the sun-burner, and in all these cases ventilation is provided for by means of this burner. The earliest gaselier of this kind consisted of a circle of ordinary butterfly or fish-tail burners hung beneath a metallic reflector, into which opened the extraction-flue for the burned gases. The first objection to this was the shadow thrown by the reflector according to the height at which it was placed. This was remedied by giving the apparatus the form shown in Fig. 7283, which is still in common use. The second objection was the down-draught of cold air, which disturbed and sometimes extinguished the jets. To obviate this a valve was provided, which closed the extraction-flue at the same time as the gas-cock, and the top of the extraction-flue was protected from the wind by a cowl or a similar covering. In the accompanying figure the flue is vertical; the upper portion near the ceiling is perforated to admit the vitiated air of the apartment. When the burner is recessed into the ceiling, it is surmounted by an iron dome, perforated to allow the burned air to pass through. Fig. 7284 represents a form very extensively employed in London hotels and shops. The gas-pipe descends inside, and the vitiated air is carried off through the bottom and top of the burner. The extraction-flue in this case is horizontal, and is carried along within the thickness of the floor above to a chimney. This is a much better arrangement, as it places the extraction-flue under the influence of the suction of the chimney. In the case of a dwelling-room, this chimney should be one in which there is a constant fire, if the gas-flue is the only one provided for the escape of the vitiated air, otherwise the ventilation will in a great measure cease when the gas is extinguished. The utilization of the gas-flues has only recently been seriously considered, and it must be acknowledged that it is yet in a tentative state.

7283.



7284.



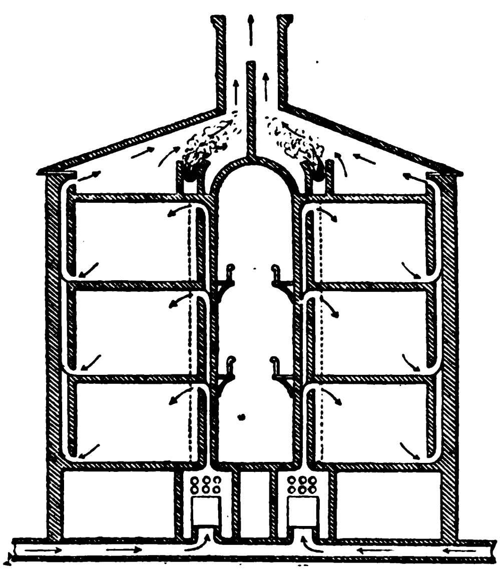
The Ventilation of Barracks and Prisons.—In the sanitary arrangements of barracks, ventilation

should occupy the foremost place. Here we have a large number of men congregated, and at night thickly crowded into small sleeping apartments. The rooms are usually badly lighted and sparely provided with fire-places. The water-closets and urinals are generally in a filthy state, polluting the air with effluvia of a dangerous character, and even the badly-constructed joints in the paving of the courtyards are filled with decaying organic matters. Moreover, the supply of water is never very abundant, and the use of it is more limited still. The ablutions of a private soldier seldom extend beyond his face and hands, the brightness of his weapons being considered by his superiors of more importance than the cleanliness of his body. These causes lead to the frequent outbreak of virulent diseases, and it is incumbent on all who have authority over the sanitary regulations to render the causes inoperative by providing an efficient ventilation. It is not necessary that we should give an example of a system applicable to barracks. The conditions vary so much that it is hardly possible to devise a plan that shall be suitable to all cases; circumstances will determine the most fitting arrangements. If the principles we have discussed be borne in mind, the foregoing illustrations will be amply sufficient to enable the sanitary engineer to design a system that shall be applicable to a given case.

The ventilation of prisons requires a system similar in its general arrangements to that in use in hospitals. The first important application of the plan of admitting the fresh air at the top of the room and extracting it at the bottom was applied to the model prison at Pentonville, and published in 1844 by Major Webb. The objects proposed were—1, to provide each prisoner with a sufficient quantity of cold or warm fresh air without causing a draught; 2, to effect the displacement of an equal quantity of vitiated air; and 3, to avoid all communication between the prisoners by the transmission of sound.

The system adopted to attain these objects is shown in Fig. 7285. In the cellars beneath the building are placed boilers, from which hot-water pipes run beneath the floors and passages of the ground story. From thence, separate warm-air ducts for each cell run up to a grating in the ceiling beyond the reach of the occupants. On the opposite side of the cell near the floor is the aperture for the escape of the vitiated air, which aperture is in communication with a separate flue through which the air is conveyed up to a collector beneath the roof. Here the fires of the establishment are utilized to give the requisite suction, and special stoves provided for use when occasion requires it. The same system has been applied to the prison of Mazas in Paris.

7285.



Warming.—The human body is a furnace, in which combustion is constantly going on. This combustion is the sole source of heat to the body. It is altogether erroneous to suppose that we derive heat from the medium in which we are placed. On the contrary, the medium, being at a lower temperature than our bodies, abstracts heat from them. When we enter from a cold atmosphere into a warm room, we are apt to think that our bodies are absorbing heat from the warm air of the room. But if we reflect that the temperature of the human body in health is always about 100°, whether the climate be frozen or tropical, and that the temperature of a room is always considerably less than 100°, we shall at once see that the warm atmosphere of the room must abstract heat from our bodies as the cold external atmosphere did; the only difference is that one abstracts it much more rapidly than the other. It is the sudden reduction of the rate of abstraction that causes the sensation of warmth. When the air in contact with the body is at a low temperature, it abstracts heat rapidly, and thereby causes a sensation of cold, and it is to reduce the rate of abstraction that it becomes necessary to warm the air in winter, and to increase the quantity of clothing. The combustion above alluded to is at all times sufficient to produce an excess of heat. If the temperature of the atmosphere is at 100°, it is incapable of abstracting any, and in such a case, even when sitting still, the heat is intolerable. Consequently the temperature of the atmosphere of a dwelling-room should be such as to allow the abstraction of the excess and no more; for if it abstract more, we feel cold, and if less, we are uncomfortably warm. This temperature has been found to be from 63° to 66°, and it is to maintain this temperature that the various systems of warming are employed. The maintenance of a due degree of warmth is as necessary to health as an efficient ventilation, and it should therefore be considered in conjunction with the latter.

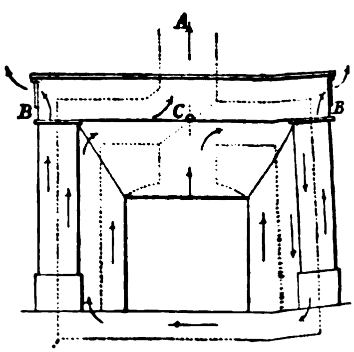
In treating of ventilation, we described the various modes of warming the air before admitting it into the room, and as the whole question of warming lies in this, it only remains for us to describe the several kinds of apparatus by means of which the warming is effected. These apparatus may be classed under the heads of the grate, the stove, gas, steam, and hot water.

The grate is so well known that it needs no description. It is by far the most wasteful of fuel. Dr. Arnott calculated that not more than one-eighth part of the heat generated was thrown out into the room, the rest being carried up the chimney. Notwithstanding its wasteful character, it is by

far the greatest favourite in England. This is due to its air of cheerfulness and comfort, and its power of concentrating the whole family in one social circle, a power that has rendered the fire-side almost an object of worship. There is, however, a liability to err in respect to the question of waste heat. When discussing the merits of the several kinds of fire-places, it is customary to speak of the heat which escapes from a grate up the chimney as representing so much fuel absolutely lost. Such is far from being the case. The heat that passes up the chimney performs a very important work by producing the suction requisite for the extraction of the vitiated air. Therefore the heat which escapes into the chimney, instead of being considered as waste, should be regarded as so much motive power necessary to ventilation. There is no doubt, however, that the power thus afforded is greatly in excess of what is needed, and for this reason grates must be considered as very wasteful of fuel. Numerous attempts have been made to improve them in this respect, some of which have been fairly successful.

When a fire is kindled in a fire-place, the heat produced by the combustion is divided into two parts, one of which is utilized to warm the apartment—1, by radiation; 2, by the reflection of the rays from the surfaces of the fire-place; and 3, by the hot-air chamber when there is one, which heat is sometimes called heat of transmission; while the other part passes into the smoke-flue, where it serves the two important purposes of ridding the room of the products of combustion and of promoting ventilation. These latter purposes every kind of fire-place must efficiently accomplish; the objection which lies against the open grate is that too much of its heat, often as large a proportion as 90 per cent., is turned to this account. Now, a sufficient draught is produced to effect the purposes indicated above if there is a difference of temperature of 25 or 30 per cent. between the column of air in the chimney and that of the external air. But as it is frequently necessary to produce a stronger suction than would result from this difference of temperature in order to reduce the sectional area of the inlet air-ducts, we may assume that there should be a difference of 40 per cent. As only about 10 per cent. of the heat produced is utilized in the room by direct and indirect radiation, we see at once that a large proportion is absolute waste. To remedy this costly defect of the open fire there are two means available, namely, a more effective arrangement of the radiating surfaces, and a fuller utilization of what we have designated as the heat of transmission. One improvement consists in diminishing the quantity of metal in contact with the fire; for as iron is an excellent conductor of heat, it passes the heat into the wall as fast as it is generated, a fact that is rendered clearly apparent by the surface of the coals in contact with the iron being always black. This improvement is effected by forming the back and sides of fire-bricks. The form of the grate is also deserving of attention. The object being to present a large surface of glowing heat at the front, the grate should be made long and deep in proportion to its width from front to back. This principle must, however, not be carried too far, or the stratum of coal will be so reduced in thickness as to burn imperfectly. Another important matter is the shape of the chimney-mouth or recess above the grate. If the sides are square with the back, it is evident that no portion of the heat falling upon them can be thrown out into the room. To render this heat available, the sides, or covings as they are technically termed, should make an angle of about 130° with the back. Usually these covings are made of curved iron, and polished to reflect the heat; as, however, they speedily become covered with soot, it is doubtful whether they utilize the heat falling upon them to the degree that bricks would do. The conductivity of the metal transmits the heat to the wall behind, where it serves no useful purpose, but bricks would radiate it when they became sufficiently heated. Much depends also on the dimensions of the chimney-throat, which should be just sufficient to allow a passage for the burned and vitiated air and the smoke, and no more; for if larger dimensions be given it, the warmed air of the room will be carried away too rapidly. To regulate the size of this opening is the object of the register in the register-grate. All the numerous forms of grate recently introduced have been constructed on these principles. We shall not attempt the endless and unprofitable task of describing all these new inventions, but will content ourselves with merely directing attention to one form in which the fuel, instead of being placed on the top of the fire, is supplied to it from below. The chief advantage of this system is that combustion is complete, the smoke being wholly consumed by the glowing mass of coals above, through which it is forced to pass. By this means fuel is economized, and the outside atmosphere is rid of one polluting cause.

7286.



The utilization of the excess of heat, which, in spite of every improvement effected in the grate and the chimney-mouth, will pass up the chimney, offers the most promising field to inventive genius. We have already described incidentally the various modes of employing this heat to warm the air previous to admission, and so far such systems are satisfactory. But as this excess of heat is always large, more of it might be made available for radiation into the room by passing it through one or more convolutions of passage behind the chimney-piece, or in some other position, before admitting it into the chimney. An excellent plan of effecting this has been proposed by Joly, and is shown in Fig. 7286, which we take as an illustration of what may be accomplished in this way.

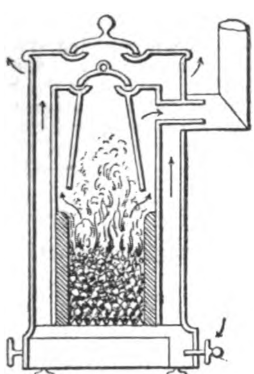
When the fire is first lit the damper C is opened, and the smoke allowed to pass directly up into the chimney A. But as soon as the draught is well established, the damper is closed, and the burned air and smoke made to pass down behind the chimney-jambs, beneath the hearth, and up again on the other side, as shown in the figure, before being admitted into the chimney, after the manner adopted in Russian stoves.

The incoming air is warmed by being made to pass up in contact with the flue, as shown at B. With such an arrangement there would be very little waste of heat.

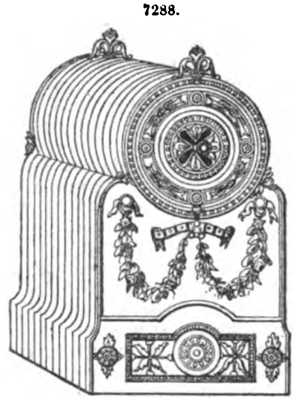
Stoves.—By the term stove is generally understood an enclosure of metal, brick, or earthenware constructed to contain a fire, and placed away from the wall of the room. Though the open fire continues to be in favour in England, in other countries, especially where fuel is scarce, the stove is in almost universal use. For simply warming an apartment, the stove possesses an enormous advantage over the grate, inasmuch as it utilizes from 80 to 90 per cent. of the fuel. But it must be borne in mind that this economy is purchased at the cost of ventilation. As a writer has well remarked, nothing is easier than to warm a close apartment. Shut a man in it, and supply him with food, and his body will be a stove sufficient to warm the atmosphere, the only drawback to this method being that the man's death from suffocation will only be a question of time. A similar objection lies against the stove; it tends to promote suffocation. Other objections are, its liability to become overheated, and to burn the air, and its want of the cheerful aspect possessed by the open fire. The unwholesomeness of the stove has, however, been removed to a very great extent. If due precautions are taken to carry off the noxious products of combustion and to prevent the surfaces from becoming overheated, the stove may be made to do useful service, both in warming and in ventilating an apartment. The conditions which must be fulfilled in the construction of a stove to render it both wholesome and efficient are the following;—The fire-box must possess dimensions proportionate to the heating surface, and be so arranged that no portion of the surface in contact with the air may be overheated. The smoke-passage must be unobstructed, and of a diameter proportionate to the fire-box and the degree of ventilation which it is required to produce, and an evaporating surface must be provided to maintain a proper degree of moisture in the atmosphere.

The numerous inventions of recent years have all been attempts to realize these conditions. The means employed to avoid overheating the surface is to line the fire-box with bricks, and to enclose it in several casings, by which means the heating surface is increased. The earliest successful attempt to improve the stove, and render it wholesome, was made in 1855 by Dr. Arnott. The Arnott stove, shown in section in Fig. 7287, has served as a model for subsequent inventors, who have done little more than improve the details of its arrangement. The feed-draught is admitted near the ash-pit door, and is regulated by a valve, which allows a slow combustion to be maintained. The coal is introduced at the top through lids, which are rendered nearly air-tight by means of sand-joints, that is, by their edges being turned down and made to dip into grooves filled with sand. The fire-box is lined with fire-bricks, as shown in the figure, to prevent such cooling of the ignited mass as might interfere with a steady combustion. The stove proper is enclosed in a case or covering, to prevent the intense heat of the former from injuring the air of the room. In this example, the coal is represented as burning from the top downwards; but in the most approved form of this stove the coal is lit at the bottom. In this case, only that portion of it which is in contact with the bars through which the air is admitted is in a state of active combustion. The unignited coal sinks down as the lower layer is consumed; thus the stove is self-feeding. A sufficient quantity of coal may be placed in the stove to last twenty-four hours, a valuable feature when it is to be used solely for ventilative purposes.

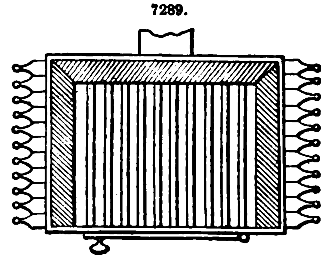
7287.



7288.



7289.



After Dr. Arnott, Sylvester, an engineer, brought out an improvement, which has produced an entire change in the construction of stoves. The new principle introduced by Sylvester consisted in multiplying the heating surfaces by means of vertical plates. The following description of the improved stove will best illustrate the principle. An elevation and a plan of the stove are given in Figs. 7288, 7289.

The fuel is placed upon a grate, the bars of which are even with the floor of the room. The sides and top of these stoves are constructed of double casings of iron, and in the sides a series of vertical plates, parallel with the front facing, are included in the interior, which collect by conduction a great portion of the heat generated by the fire, the mass of metal of which these are composed being so proportioned to the fuel consumed that the whole can never rise above the temperature of 212° Fahr. under any circumstances. The sides and top of the stove are thus converted into a hot chamber, offering an extensive surface of heated metal. At the bottom, through an opening in the

ornamental part, the air is allowed to enter, which, as it becomes warmed, rises through the different compartments formed by the hot parallel plates, and escapes at the top through similar openings into the room.

Sylvester's idea was modified a few years later by Gurney, who produced the stove represented in Fig. 7290. It resembles Sylvester's stove in possessing the multiple heating surfaces. It differs from it, however, in form, and in not always being lined with fire-brick, overheating being prevented by placing the stove in a pan filled with water, the evaporation of which is effected with a rapidity corresponding to the activity of the combustion. It would be preferable to line this stove with brick in all cases, and a more ornamental appearance might be given to it by substituting a vase, conveniently placed on the top, for the somewhat unsightly pan at the bottom. This stove possesses the undoubted merit of having popularized the use of the plates or ribs first introduced by Sylvester.

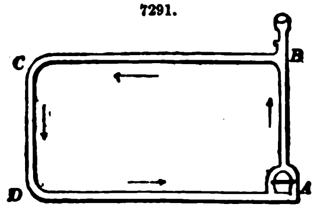
7290.

When a stove is employed solely to warm the air before being admitted into an apartment, it is termed a hot-air stove, and its construction is modified to render it suitable to the purpose intended. Stoves applied to this use generally consist of a fire-box, smoke-pipes in one or more convolutions, a casing enclosing the hot chamber, and hot-air pipes running from the top. But the details admit of an infinite variety in the arrangements, and it would therefore be futile to attempt a description of them. We have already shown some of these arrangements when treating of ventilation.

When large spaces have to be warmed, such as the interiors of public buildings, it is obvious that a single radiating stove, whatever its dimensions may be, must be quite inadequate to the purpose; for the distant parts of the room would remain cold even after the heat in the immediate neighbourhood of the fire had become intolerable. To increase the number of the stoves would entail great additional labour and expense, and in many cases would be altogether impracticable. Hence it is necessary to employ means of transmitting the heat from one fire and of distributing it equally over the whole space. The means used for this purpose are hot air, hot water, and steam, to which, as applicable to certain cases, may be added gas, though the latter must be considered as a substitute for several fires, rather than a means of transmitting heat from one fire. Hot air possesses the great advantages of being extremely simple and cheap in its application, and of ensuring an adequate and perfect ventilation; but it is open to the grave objection of rendering the air unwholesome by overheating it. As we have previously explained, air suddenly heated is unwholesomely dry; but besides this, when air is passed over metal in a state of intense heat, the organic matters floating in it are burned, causing the unpleasant smell which air so treated always possesses. This objection, however, lies rather against the details than against the principle of the system. If the air, instead of being brought into contact with a small surface intensely hot, were passed over a much larger surface at a correspondingly lower temperature, the same effect of warming would be produced without the unwholesome consequences that attend the former case. The various modes of distributing the warmed air have been already described.

Hot water is by far the most generally employed means of warming buildings. Its application to this purpose seems to have been first suggested by John Evelyn, who, in his Kalendarium Hortense, proposed, as early as 1675, to employ it to warm hothouses for plants. In Evelyn's plan, which is illustrated by drawings, we find all the elements of our present system of warming and ventilating by hot water, and the details are skilfully arranged. But it does not appear that the system made any progress in his time, for we next hear of it in 1816, as introduced into England by the Marquis de Chabannes from France, where it had been employed since 1777 by Bonnemain for the artificial hatching of chickens. Since that time it has continued rapidly to develop itself. The principle of this mode of conveying heat is a very simple one. Suppose a circuit of pipes A B C D, Fig. 7291, in which a furnace is placed at A and an expansion vessel at B; the water in this circuit will remain in a state of absolute rest, because the columns A B and D C are of equal density. Suppose now a fire made in the furnace at A; the column A B will be heated, and consequently its density lessened, and the equilibrium of the two columns will be destroyed; the portion D A will be driven towards the furnace with a force proportionate to the difference of density in the two vertical columns. If now we conceive the columns B C and A D produced, it will be evident that heat may be transmitted through them to a considerable distance. Moreover, it is obvious that if the pipes are made of a good conducting material, as iron, and are coiled or multiplied in their course, they will give off their heat in a degree directly proportionate to the extent of their surfaces and the temperature of the water relatively to that of the surrounding atmosphere.

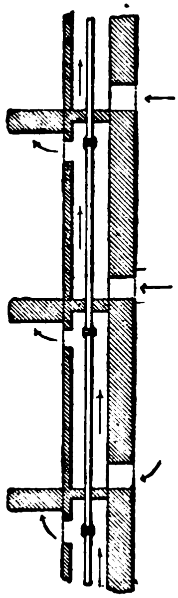
7291.



As the heat from the pipes affects the circulation of the air in the room, the pipes must be disposed in accordance with the system of ventilation adopted. Obvious as it may seem, this precaution is frequently neglected, and the consequence of such ignorance is cold draughts in every part of the room. There are various ways of arranging the hot-water pipes. Very often they are placed horizontally, either upon the floor against the walls of the apartment to be warmed, or beneath the floor; in the latter case, a grating is placed in the floor directly over the pipes. This arrangement is the usual one adopted in churches. Sometimes the pipes are fixed vertically in special flues in the walls, as shown in Fig. 7292; in this case, an opening is provided in the flue at the top and bottom of each apartment to allow of the joints being inspected, and to afford a passage for the

ventilative currents. Another arrangement, and one that in numerous cases is by much the best, is to place the pipes in coils, or some other suitable manner, in the basement of the building, and to employ them instead of air-stoves to heat the incoming ventilative current. By this means all the advantages of the hot-air system may be obtained, without the defects which we have previously pointed out. An arrangement of this kind has been described in connection with the ventilation of St. Thomas's Hospital, and at the Houses of Parliament a similar plan is carried out by means of steam. The best means of combining the warming with the ventilating of an apartment, or set of apartments, and it is impossible to separate these without producing greater evils than the warming is designed to avoid, is undoubtedly afforded by hot air. As we have already pointed out, the objections to the latter system lie, not against the principle of it, but against the mode of heating the air; and if hot water were substituted for the hot-air stove, every objection on the score of unwholesomeness would be removed. Drs. Drysdale and Hayward, whose system of warming and ventilating has already been described, condemn the mode of warming with hot air as being unwholesome, but they admit its superiority over every other mode by practically adopting it; for though they employ hot water, they do so only to warm the incoming ventilative current. An advantage possessed by the hot-water over the hot-air system is that it may be more easily applied to an existing building. The form of the furnace and the arrangement of its details admit of endless variety. The object to be attained is the same as in a steam-boiler, and the means employed must thus be similar.

7292.



To avoid the necessity for so large a mass of water and such an extent of heating surface, the high-pressure system was introduced by Perkins. In this system the pipes are made very small and very strong, frequently 1 in. outside and ½ in. inside diameter, and always of wrought iron. These pipes are formed into an endless circuit and hermetically closed, and the water is made to circulate through them rapidly at a temperature of 300° and upwards. The furnace is enclosed in brick, and the water is heated by passing a number of coils of the pipe through the furnace. At the highest part of the circuit is an expansion vessel, also shut off from the atmosphere, and allowing an expansion of 15 or 20 per cent. The pipes may be carried through the building in the same way as in the low-pressure system already described. A common arrangement is to place a considerable coil in a pedestal or bunker with open trellis-work in front, in a convenient part of the room. From the smallness of the pipes employed in this system, they can be readily placed in position without injury to the floors and walls. The mode of increasing the heating surface by coils is also an advantage. The objections to this system are its expensiveness, which is a great obstacle to its general adoption, and the liability of the pipes to burst.

The great capacity of water for heat, and the permanence of its circulation even long after the fire in the furnace has been extinguished, ensure a regular temperature in every part of the room in spite of interruptions of the furnace fire, and constitute one of the greatest advantages of the hot-water system. Also heat can be conveyed by means of water to a great horizontal distance, which it is hardly possible to do with hot air, and the air is never overheated as it frequently is by stoves. Other advantages possessed by the system are its economy of fuel, the facilities it offers for the constant supply of hot water for baths and lavatory purposes, the ready means it affords for effecting an adequate and suitable ventilation, and the surety it gives against fire, and the lesser but great evil of smoky chimneys. On the other hand, its first cost is considerable; it is very slow in its action on account of the mass of water to be heated, and it lacks the cheerful appearance of the open fire.

Steam possesses several advantages over hot water that has led to its adoption in many public buildings. In factories, workshops, and all places where steam power is employed, it affords the readiest, the most efficient, and the cheapest means of warming, because the steam may be taken directly from the boiler. Where, however, a special boiler has to be provided, the cost is usually greater than that of water. Warming by steam is founded on the property which steam possesses of being suddenly condensed when brought into contact with a cold surface, and at the same time of giving out its latent heat, which is communicated to that surface. The condensing vessel is usually a pipe placed in a suitable position in the room to be warmed. The circuit of pipe is so disposed that the water derived from the condensation of the steam is conveyed back to the boiler. The chief advantages of steam as a means of warming, consist in the rapidity with which heat may be conveyed to and cut off from a given point; the great quantity of heat that may be conveyed, and the consequent small dimensions of the pipes required.

To ensure a successful working of the system, the details must be carefully planned and executed, and the extent of heating surface must be calculated according to the size of the room, the thickness of the walls, the number of windows, the northern or southern aspect, or any other source of loss of heat. In making this calculation of the requisite surface of steam-pipe, it is usual to allow 1 sq. ft. for every 6 sq. ft. of single-glass window of the ordinary thickness; 1 sq. ft. for every 120 sq. ft. of wall, floor and ceiling of ordinary material and thickness, and 1 sq. ft. for every 6 cub. ft. of hot air escaping a minute as ventilation. The first cost of steam apparatus is less than that of hot water, on account of the small dimensions of the pipes required; and provided the details are planned and executed properly, there will be no risk of leakage, nor any danger to be apprehended of explosion, as the condensed water returns immediately to the boiler through pipes suitably placed. As the pipes occupy even less space than Perkins's high-pressure hot-water pipes, the advantages afforded by the latter in this respect are realized in a higher degree by the use of steam.

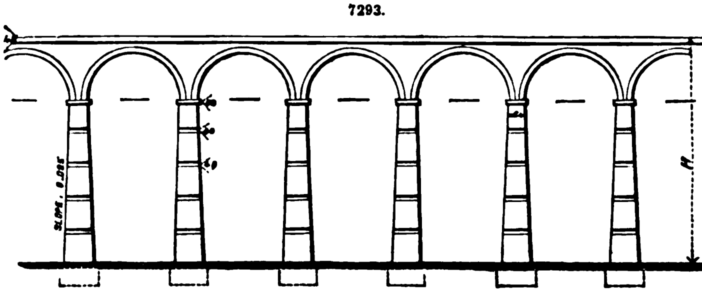
Gas has not yet been applied systematically to the warming of the atmosphere of an apartment. It possesses, however, qualities that render it very suitable for this purpose, and it is probable that a future generation will turn on heat, as we now turn on light, by means of this valuable agent.

Books on Warming and Ventilating:—Inman (W. S.), 'Report on Ventilation, Warming, and the Transmission of Sound,' 8vo, 1836. Tredgold (T.), 'Principles of Warming and Ventilating Public Buildings,' 8vo, 1836. Péclet (E.), 'Traité de la Chaleur,' 3 vols. royal 8vo, Paris, 1843. Reid (D. B.), 'Theory and Practice of Ventilation,' 8vo, 1844. Bernan (W.), 'History of the Art of Warming and Ventilating,' 2 vols. 12mo, 1845. Arnott (N.), 'The Smokeless Fireplace,' 8vo, 1855. Morin (Gen.), 'Études sur la Ventilation,' 2 vols. 8vo, Paris, 1861. Ritchie (R.), 'On Ventilation, Natural and Artificial,' 8vo, 1862. Box (Thos.), 'Practical Treatise on Heat,' crown 8vo, 1868. Hood (C.), 'On Warming Buildings and on Ventilation,' 8vo, 1869. Eassie (W.), 'Healthy Houses,' 12mo, 1872. 'Health and Comfort in House Building,' by Drs. J. Drysdale and J. W. Hayward, 8vo, 1872. Joly (V. Ch.), 'Traité Pratique du Chauffage et de la Ventilation,' royal 8vo, Paris, 1873. Reid (D. B.), 'On Ventilation in American Dwellings,' 8vo, New York.

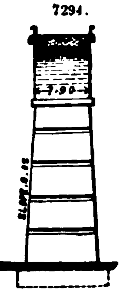
VIADUCT. Fr., *Viaduc*; Ger., *Viaduct*; Ital., *Viadotto*; Span., *Viaducto*.

Though strictly speaking embankments, cuttings, and tunnels are viaducts, the term is generally understood to apply only to elevated roadways supported upon artificial constructions of stone, iron, or timber. Thus a viaduct may be defined as an extensive bridge, or series of arches, erected for the purpose of conducting a road or a railway above the level of the ground in crossing a valley, or any place where it may be necessary to conduct the road or the railway at the requisite elevation above the natural surface of the ground, in order to avoid interference with previously existing lines of communication. The wide extension of the railway systems, and the imperative necessity in their construction for preserving a horizontal level for the roadway, or at least of departing from this level within very restricted limits only, have rendered the construction of viaducts an important part of railway engineering. When the necessity occurs for raising the line to a height considerably above the natural level of the ground, various considerations may arise to influence the engineer in his choice between an embankment and a viaduct. If the height be great, or the subformation of the valley of a very unstable nature, an embankment is scarcely practicable, and therefore valleys, whether having a stream in them or not, are almost always crossed by viaducts. In other cases, appearance and economy must be considered. An embankment, by cutting off the view beyond, may destroy the value of a site that without it would be picturesque. This consideration in some instances may be an important one; but usually the question is decided on the ground of economy. An embankment covers a wider base than a viaduct, and covers it too in a more absolute manner, for it must be borne in mind that the space beneath a viaduct may often be profitably utilized. Want of cohesion in the materials causes an embankment to subside under the heavy loads that are continually passing over it, and from the effects of heavy rains. This latter cause also

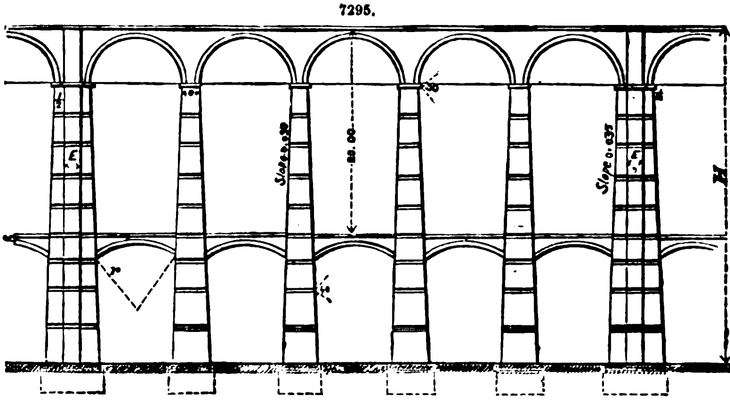
7293.



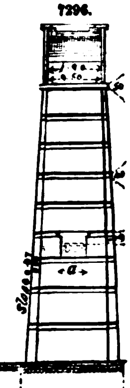
7294.



7295.



7296.



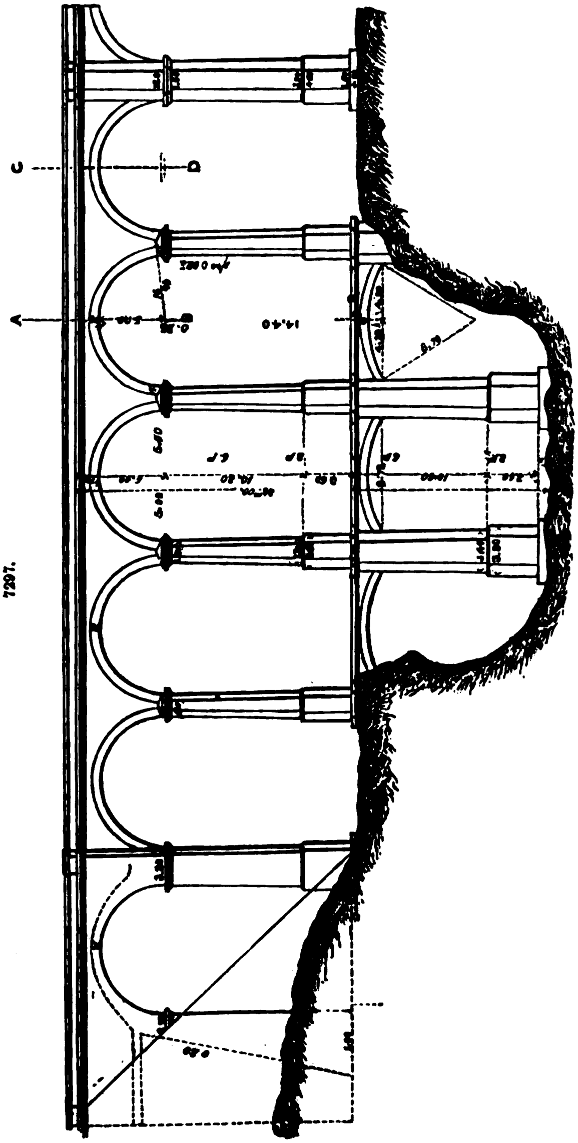
operates to wear away the sides and other exposed surfaces. Thus the question of repairs becomes a serious one, and often leads to the choice of the viaduct as involving less expense for construction

and maintenance. This is especially the case in the neighbourhood of towns where a railway has to be brought in on a level sufficiently elevated to enable it to pass over the streets. The outskirts of London contain numerous examples of this mode of carrying a line of railway.

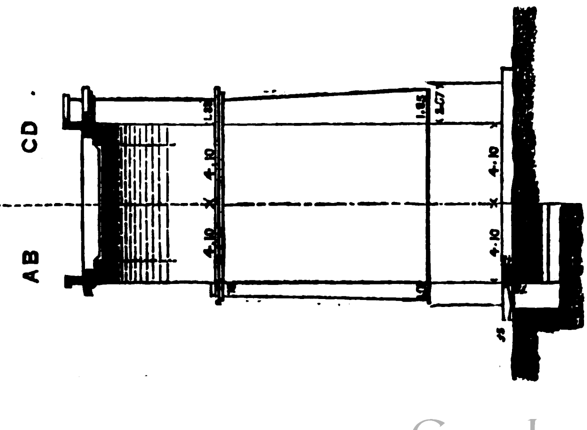
As a viaduct is nothing more than an extended bridge, we need not enter here into a consideration of the principles of its construction, which, being precisely similar to those of a bridge, have been fully treated in another article. The only difference of construction in the details of the viaduct is due to the great height of the piers which this structure frequently requires. This circumstance renders it necessary to tie the piers between the ground line and the springing of the arches. This is effected by throwing a light arch from one to the other, as shown in Figs. 7295, 7297. These Figs. 7293 to 7298 are given as simple types of stone-viaduct construction. The two former have each a constant breadth of 25 ft. 6 in., which is sufficient for a double line of rails. The faces of the spandrils are vertical; the piers are solid and have no insets in any part, but to compensate this their batter is considerable, being ·035 in the longitudinal and ·05 in the transverse section. The bonding of the masonry is strengthened by courses of ashlar-work extending through the pier at intervals of about 12 ft. All the salient angles have stone dressings. When the height of the piers is great, they are tied or rather buttressed, since there can be no tensile strain, with light segmental arches varying in breadth from 11 ft. to 14 ft. 6 in., according to the size of the principal arches. This buttress arcading is situate about 60 ft. below the springing of the arches. In the type represented in Fig. 7295, every fifth pier is strengthened with a central mass of masonry, the thickness of which is constant for the whole height, but which varies from 5 to 8 ft. according to the requirements of the load and the thrust. In the side elevation this central portion forms projecting counterforts.

There are numerous fine examples of timber viaducts in existence. One on the line of the Richmond and Petersburg Railway, in North America, has a total length of 2900 ft., and is constructed on the truss principle. The truss frames, which are horizontal on top and bottom, are 20 ft. deep, and are supported upon eighteen granite piers standing 40 ft. above the water, at distances apart varying from 130 to 153 ft. A similar structure crosses the Susquehannah, and is 2200 ft. in length, each span being 220 ft.

7297.



7298.



Among the finest examples existing in England may be mentioned two on the Newcastle and Tynemouth Railway. One of these structures crosses the Ouse bourne, a public roadway, a mill-race, and the adjacent valley. It consists of five wooden arches, three of which are 116 ft. span and two 114 ft., and four end arches of masonry, two having a span of 43 ft., and the two others 36 ft.; the total length of the viaduct being 918 ft. It carries a double line of rails in a breadth of 26 ft., and a footway 5 ft. broad; the height of the rails above the bed of the bourne is 108 ft. The piers are of masonry, and have a considerable batter, the principal being 21 ft. wide at the footings and 15 ft. at the springing of the arches; they are continued, with reduced dimensions, up to the level of the roadway. The construction of the wooden arches is worthy of special attention. The ribs of which they are composed are of kyanized Dantzic deal, and they are turned to a radius of 68 ft., the rise being about 33 ft. The planks of which these ribs are made up are 11 in. wide by 3 in. thick, and are in lengths varying from 20 to 46 ft. In building up the rib, these planks are laid two whole ones in one course, and one whole one and two halves in the next course, care being taken to cross the joints both longitudinally and in depth. The number of courses so formed is fourteen. To fix these courses together, oak treenails 1½ in. in diameter were used at distances of 4 ft. apart, each treenail passing through three of the deals. The latter were bent to the required form over a centre. To keep the joints perfectly tight, a layer of brown paper, previously dipped in boiling tar, was placed in them. The spandrils of these arches are formed of trussed framings. The flooring, which is of 3-in. planking over transverse beams 4 ft. apart, is covered with a composition impervious to water. The dimensions marked on Figs. 7293 to 7297 are metric.

On the Cornish Railway there are numerous examples of timber viaducts that are deserving of a careful study.

VICE. Fr., *Étau;* Ger., *Schraubstock;* Ital., *Morsa;* Span., *Tornillo.*

See Hand-Tools.

VIRTUAL VELOCITY. Fr., *Vitesse virtuelle;* Ger., *Virtuelle Geschwindigkeit;* Ital., *Velocità virtuale;* Span., *Velocidad virtual.*

Virtual velocity is a minute hypothetical displacement, or motion, assumed in analysis to facilitate the investigation of statical problems. With respect to any given force of a number holding a material system in equilibrium, it is the projection upon the direction of the force, of a line joining its point of application with a new position of that point conceived to be taken indefinitely near to the first, and without disturbing the equilibrium of the system, or the connection of its parts with each other. The *principle of virtual velocities* is the law that when several forces are in equilibrium the algebraic sum of their virtual moments is equal to zero. The *virtual moment* of a force is the product of the intensity of the force multiplied by the virtual velocity of its point of application.

VIS VIVA. Fr., *Force vive;* Ger., *Lebendige Kraft;* Ital., *Forza viva;* Span., *Fuerza viva.*

Living force, or *vis viva*, is the force of a body moving against resistance, or doing work, in distinction from *vis mortua*, or dead force. It is expressed by the product of the mass of a body multiplied by the square of its velocity. The *principle of vis viva* is the principle that the difference between the aggregate work of the accelerating forces of a system and that of the retarding forces is equal to one-half the *vis viva* accumulated or lost in the system whilst the work is doing. The term *vis mortua* is not often used, and implies force doing no work but only producing pressure. *Vis inertiæ* is the resistance of matter, as when a body at rest is set in motion, or a body in motion is brought to rest, or has its motion changed either in direction or in velocity; it also means inertness; inactivity. *Vis inertiæ* and inertia are not strictly synonymous, as the former applies to the resistance itself which is given, while the latter applies merely to the property by which it is given.

WARMING. Fr., *Chauffage;* Ger., *Heizung;* Ital., *Riscaldamento;* Span., *Calefaccion.*

See Ventilation.

WATER-WORKS. Fr., *Conduite et Distribution des eaux;* Ger., *Wasserbitung;* Ital., *Condotta di acqua potabile;* Span., *Obras hidraúlicas.*

One of the primary wants of human life is a constant supply of wholesome water; and it is a chief duty of the hydraulic engineer to collect and convey economically stores of water, from either natural or artificial reservoirs, to communities which without water could not exist. Rain is the great source of all fresh water, and when it has fallen it presents itself in the forms of surface waters, rivers, streams, and natural springs; but may also be obtained from wells and impounding reservoirs, artificially formed, or from a combination of two or more of the sources named. As it is useless to entertain any scheme for supplying water without ascertaining the composition and quality of all the waters liable to be drawn upon, a careful analysis must be made, and the purest available source selected.

Analysis.—A great difficulty with water analysis is, to satisfactorily prove the sanitary effect of certain impurities contained in the water,—that is, to show connection between the results of an analysis, and the physiological effects produced by the use of that water. This arises from our knowledge of the subject being less definite than could be wished. Thus, the good or bad effect of moderately hard waters containing chalk is an open question; and although waters containing sewage, metals, living organisms, animal refuse, or salts, in excess, are decidedly objectionable, waters having traces of them may be used with impunity. It is, however, generally recognized that water can be considered good and potable when it is fresh, clear, without odour; when its savour is very weak; when it is especially neither distasteful, salt, or sweetish; when it contains little of extraneous matters; when it is sufficiently aërated; when it dissolves soap without forming clots; and when it cooks vegetables well.

Any glass-stoppered bottle, holding two or three quarts, will serve for collecting the sample to be examined, care being exercised that the bottle is quite clean. In collecting the water from a river or tank, the bottle should be immersed below the surface, and rinsed once or twice with the water; and in taking the water from a pump or pipe a quantity should be allowed to flow away

before the sample is collected. The bottle is filled up nearly to the neck, and the stopper tied over with a piece of linen, no luting or wax being used.

As a Preliminary Examination.—Fill a flask of white glass with the water to be examined, and compare its colour with that of distilled water contained in a similar flask. Warm some of the water slightly in a test-tube; shake it, and observe if the water possesses any peculiar odour or taste. Warming will often disclose the smell of a water when none could be noticed cold.

A rough method of estimating the suspended matters is to pass a known quantity of water through a filter paper previously washed in distilled water. The increase in the weight of the filter paper gives the quantity of total suspended matter in the known volume of the water. Burn the paper, and weigh the ash; then burn an unused filter paper previously ascertained to be precisely similar to that used, and also weigh its ash; the quantity of ash in excess of that contained in the unused filter gives the amount of suspended inorganic matter in the water.

Estimation of the Ammonia.—It is desirable to proceed at once with the determination of this constituent, since it is the most liable to change. The method of estimation is based upon the fact that an alkaline solution of mercuric iodide, added to a liquid containing ammonia, produces a brown coloration, due to the formation of the iodide of tetramercurammonium. This test, known as Nessler's, is capable of detecting one part of ammonia in 20,000,000 parts of water.

Preparation of the Nessler Test.—Dissolve 35 grms. of iodide of potassium in water, and add, little by little, a cold concentrated solution of corrosive sublimate, until the precipitate disappears on stirring. Cautiously continue the addition of the corrosive sublimate solution until a very slight precipitate only remains. Filter, and add to the filtrate an aqueous solution of caustic soda, prepared by dissolving 100 grams. of stick potash in 200 cub. cent. of water, and dilute the mixture; to this is added a tenth part of a weak solution of bichloride of mercury. The liquid should be allowed to stand for a short time, and a portion decanted for use. The test requires, in addition to the use of distilled water without ammonia, a standard solution of ammonia, containing $\frac{1}{100}$ milligramme of ammonia to each cub. cent. of water; and graduated glass cylinders.

Transfer 100 c.c. of the water to be tested to one of the glass cylinders; add $1\frac{1}{2}$ c.c. of the Nessler solution, and agitate. Notice the colour, and then pour as much of the solution of ammonia as may be considered equivalent to it into a second cylinder, and fill up with 100 c.c. distilled water; add $1\frac{1}{2}$ c.c. of Nessler solution. Mix thoroughly, and compare the tints in the two cylinders. If they are about equal in intensity, the quantity of ammonia used will equal the ammonia in the water that is being examined. Observe whether the natural water becomes turbid after the addition of the Nessler test. A decided precipitate is due to lime or magnesia salts, and indicates hardness.

Wanklyn and Chapman are of opinion that the usual methods employed to determine organic matter in water are inadequate for the purpose; and in their Treatise upon Water Analysis, which we quote, they give a new method of determining nitrogenous organic matters. It is distinguished by its special adaptation to detect and estimate microscopic quantities, and appears to be especially adapted to deal with the organic impurities in water.

Most kinds of water contain ammonia, or ammoniacal salts, which either was recently, or may presently become, a constituent of organic matter. In addition to this, most kinds of water actually do contain more or less nitrogenous organic matter, which furnishes ammonia either on simple boiling with carbonate of soda, or else on boiling with permanganate of potash, in presence of excess of alkali. By estimating the amount of ammonia obtainable from water, noting the circumstances under which it is obtained, we have a measure of the nitrogenous organic matter present in water.

We have seen the wonderful delicacy of the means of estimating and detecting ammonia. Such being the character of this estimation, the great advantage of causing determinations of organic matter to depend on measurements of ammonia will be manifest. By making these measurements of ammonia stand for measurements of organic matter, we apply micro-chemistry to water analysis.

The following is an outline of Wanklyn and Chapman's ammonia method of water analysis;—Half a litre of water is taken and placed in a tubulated retort, and 15 c.c. of a saturated solution of carbonate of soda added. The water is then distilled until the distillate begins to come over free from ammonia; that is until 50 c.c. of distillate contain less than $\frac{1}{100}$ of a milligramme of ammonia. A solution of potash and permanganate of potash is next added. This solution is made by dissolving 200 grammes of solid caustic potash and 8 grammes of crystallized permanganate of potash in a litre of water. The solution is boiled to expel any ammonia, and both it and the solution of carbonate of soda ought to be tested on a sample of pure water before being used in the examination of water. 50 c.c. of this solution of potash and permanganate should be used with half a litre of the water to be tested.

The distillation is continued until 50 c.c. of distillate contain less than $\frac{1}{100}$ milligramme of ammonia. Both sets of the distillate have the ammonia in them determined by means of the Nessler test, as previously described. No matter how good the water may be, it is desirable never to distil over less than 100 c.c. with carbonate of soda, and not less than 200 c.c. after the addition of the potash and permanganate of potash.

Wanklyn and Chapman give as an example of their method the following analysis of Edinburgh water, from Swanston, one half-litre taken;—

	Cub. Cent.		Ammonia. Milligrm.
1. Distillate (carbonate of soda)..	100	=	·015
2. Distillate (potash and permanganate of potash).. ..	100	=	·035
	100	=	·015
			·050

Therefore, 1 litre of Edinburgh water, from Swanston, contains 0·030 milligrm. free ammonia; 0·10 milligrm. albuminoid ammonia; or 1,000,000 parts contain 0·03 parts free ammonia, 0·10 parts albuminoid ammonia.

We are indebted to Dr. Clark for a simple method of determining the degree of hardness of a water. It consists in ascertaining the quantity of a standard solution of soap in spirit required to produce a permanent lather with a given quantity of the water under examination, the result being expressed in degrees of hardness, each of which corresponds to one grain of carbonate of lime in a gallon = 70,000 grains of distilled water, of the water. The following are the particulars of Clark's test;—16 grains of pure Iceland spar, carbonate of lime, are dissolved, taking care to avoid loss, in pure hydrochloric acid; the solution is evaporated to dryness in an air-bath, the residue is again redissolved in water, and again evaporated; and these operations are repeated until the solution gives to test-paper neither an acid nor an alkaline reaction. The solution is made up by additional distilled water to the bulk of precisely one gallon. It is then called the standard solution of 16° of hardness. Good London curd soap is dissolved in proof spirit, in the proportion of one ounce of avoirdupois for every gallon of spirit, and the solution is filtered into a well-stoppered phial, capable of holding 2000 grains of distilled water; 100 test measures, each measure equal to 10 water-grain measures of the standard solution of 16° degrees of hardness, are introduced. Into the water in this phial the soap solution is gradually poured from a graduated burette, the mixture being well shaken after each solution of soap, until a lather is formed of sufficient consistence to remain for five minutes all over the surface of the water, when the phial is placed on its side. The number of measures of soap solution is noticed, and the strength of the solution is altered, if necessary, by a further addition of either soap or spirit, until exactly 32 measures of the liquid are required for 100 measures of the water of 16° of hardness. The experiment is made a second and a third time, in order to leave no doubt as to the strength of the soap solution, and then a large quantity of the test may be prepared, for which purpose Dr. Clark recommends to scrape off the soap into shavings by a straight sharp edge of glass, and to dissolve it by heat in part of the proof spirit, mixing the solution thus formed with the rest of the proof spirit.

Process for ascertaining the Hardness of Water.—Previous to applying the soap test it is necessary to expel from the water the excess of carbonic acid; that is, the excess over and above what is necessary to form alkaline or earthy bicarbonates, this excess having the property of slowly decomposing a lather once formed. For this purpose, before measuring out the water for trial, it should be shaken briskly in a stoppered glass-bottle half filled with it, sucking out the air from the bottle at intervals by means of a glass tube, so as to change the atmosphere in the bottle; 100 measures of the water are then introduced into the stoppered phial, and treated with the soap test, the carbonic acid eliminated being sucked out from time to time from the upper part of the bottle. The hardness of the water is then inferred directly from the number of measures of soap solution employed by reference to the subjoined Table. In trials of waters above 16° hardness, 100 measures of distilled water should be added, and 60 measures of the soap test dropped into the mixture, provided a lather is not formed previously. If at 60 test measures of soap test, or at any number of such measures between 32° and 60°, the proper lather be produced, then a final trial may be made in the following manner;—

100 test measures of the water under trial are mixed with 100 measures of distilled water, well agitated, and the carbonic acid sucked out; to this mixture soap test is added, until the lather is produced. The number of test measures required is divided by 2, and the double of such degree will be the hardness of the water. For example, suppose half the soap test that has been required correspond to $10\frac{5}{10}$ degrees of hardness, then the hardness of the water under trial will be 21. Suppose, however, that 60 measures of the soap test have failed to produce a lather, then another 100 measures of distilled water are added, and the preliminary trial made, until 90 test measures of soap solution have been added. Should a lather now be produced, a final trial is made, by adding to 100 test measures of the water to be tried 200 test measures of distilled water, and the quantity of soap test required is divided by 3; and the degree of hardness corresponding with the third part being ascertained by comparison with the standard solutions, this degree multiplied by 3 will be the hardness of the water. Thus, suppose 85·5 measures of soap solution were required, $\frac{85\cdot5}{3} = 28\cdot5$, and on referring to the Table, this number is found to correspond to 14°, which, multiplied by 3, gives 42° for the actual hardness of the water.

Table of Soap-test Measures corresponding to 100 Test Measures of each Standard Solution.

Degree of Hardness.	Soap Test Measures.	Differences as for the next Degree of Hardness.	Degree of Hardness.	Soap Test Measures.	Differences as for the next Degree of Hardness.
0	1·4	..	9	19·4	1·9
1	3·2	1·8	10	21·3	1·9
2	5·4	2·2	11	23·1	1·8
3	7·6	2·2	12	24·9	1·8
4	9·6	2·0	13	26·7	1·8
5	11·6	2·0	14	28·5	1·8
6	13·6	2·0	15	30·3	1·8
7	15·6	2·0	16	32·0	1·7
8	17·5	1·9			

Rainfall.—Rain is of all meteorological phenomena the most capricious, both as regards its frequency and the amount which falls in a given time. In some places it rarely or never falls, whilst in others it rains almost every day; and there does not yet exist any theory from which a probable estimate of the rainfall in a given district can be deduced independently of direct observation. But although dealing with one of the most capricious of the elements, we nevertheless find a workable average in the quantity of rain to be expected in any particular place, if careful and continued observations are made with the rain-gauge. G. J. Symons, the meteorologist, to whose continued investigations we are indebted for our most reliable data upon the subject of rainfall, gives the following practical instructions for using a rain-gauge;—

"The mouth of the gauge must be set quite level, and so fixed that it will remain so; it should never be less than 6 in. above the ground, nor more than 1 ft., except when a greater elevation is absolutely necessary to obtain a proper exposure.

"It must be set on a level piece of ground, at a distance from shrubs, trees, walls, and buildings, at the very least as many feet from their base as they are in height.

"If a thoroughly clear site cannot be obtained, shelter is most endurable from N.W., N., and E., less so from S., S.E., and W., and not at all from S.W. or N.E.

"Special prohibition must issue as to keeping all tall growing flowers away from the gauges.

"In order to prevent rust, it will be desirable to give the japanned gauges a coat of paint every two or three years.

"The gauge should, if possible, be emptied daily at 9 A.M., and the amount entered against the previous day.

"When making an observation, care should be taken to hold the glass upright.

"It can hardly be necessary to give here a treatise on decimal arithmetic; suffice it therefore to say that rain-gauge glasses usually hold half an inch of rain (0·50), and that each $\frac{1}{100}$ (0·01) is marked; if the fall is less than half an inch, the number of hundredths is read off at once, if it is over half an inch, the glass must be filled up to the half inch (0·50), and the remainder (say 0·22) measured afterwards, the total (0·50 + 0·22) = 0·72 being entered. If less than $\frac{1}{10}$ (0·10) has fallen, the cypher must always be prefixed; thus if the measure is full up to the seventh line, it must be entered as 0·07, that is, no inches, no tenths, and seven hundredths. For the sake of clearness it has been found necessary to lay down an invariable rule that there shall always be two figures to the right of the decimal point. If there be only one figure, as in the case of one-tenth of an inch, usually written 0·1, a cypher must be added, making it 0·10. Neglect of this rule causes much inconvenience.

"In snow three methods may be adopted—it is well to try them all. 1. Melt what is caught in the funnel, and measure that as rain. 2. Select a place where the snow has not drifted, invert the funnel, and turning it round, lift and melt what is enclosed. 3. Measure with a rule the average depth of snow, and take one-twelfth as the equivalent of water. Some observers use in snowy weather a cylinder of the same diameter as the rain-gauge, and of considerable depth. If the wind is at all rough, all the snow is blown out of a flat-funnelled rain-gauge."

A drainage area is almost always a district of country enclosed by a ridge or watershed line, continuous except at the place where the waters of the basin find an outlet. It may be, and generally is, divided by branch ridge-lines into a number of smaller basins, each drained by its own stream into the main stream. In order to measure the area of a catchment basin a plan of the country is required, which either shows the ridge-lines or gives data for finding their positions by means of detached levels, or of contour lines.

When a catchment basin is very extensive it is advisable to measure the smaller basins of which it consists, as the depths of rainfall in them may be different; and sometimes, also, for the same reason, to divide those basins into portions at different distances from the mountain chains, where rain-clouds are chiefly formed.

The exceptional cases, in which the boundary of a drainage area is not a ridge-line on the surface of the country, are those in which the rain-water sinks into a porous stratum until its descent is stopped by an impervious stratum, and in which, consequently, one boundary at least of the drainage area depends on the figure of the impervious stratum, being, in fact, a ridge-line on the upper surface of that stratum, instead of on the ground, and very often marking the upper edge of the outcrop of that stratum. If the porous stratum is partly covered by a second impervious stratum, the nearest ridge-line on the latter stratum to the point where the porous stratum crops out will be another boundary of the drainage area. In order to determine a drainage area under these circumstances it is necessary to have a geological map and sections of the district.

The depth of rainfall in a given time varies to a great extent at different seasons, in different years, and in different places. The extreme limits of annual depth of rainfall in different parts of the world may be held to be respectively nothing and 150 in. The average annual depth of rainfall in different parts of Britain ranges from 22 in. to 140 in., and the least annual depth recorded in Britain is about 15 in.

The rainfall in different parts of a given country is, in general, greatest in those districts which lie towards the quarter from which the prevailing winds blow; in Great Britain, for instance, the western districts have the most rain. Upon a given mountain ridge, however, the reverse is the case, the greatest rainfall taking place on that side which lies to leeward, as regards the prevailing winds. To the same cause may be ascribed the fact that the rainfall is greater in mountainous than in flat districts, and greater at points near high mountain summits than at points farther from them; and the difference due to elevation is often greater by far than that due to one hundred miles geographical distance.

The most important data respecting the depth of rainfall in a given district, for practical purposes, are, the least annual rainfall; mean annual rainfall; greatest annual rainfall; distribution of the rainfall at different seasons, and, especially, the longest continuous drought; greatest flood rainfall, or continuous fall of rain in a short period.

The available rainfall of a district is that part of the total rainfall which remains to be stored in reservoirs, or carried away by streams, after deducting the loss through evaporation, through permanent absorption by plants and by the ground, and other causes.

The proportion borne by the available to the total rainfall varies very much, being affected by the rapidity of the rainfall and the compactness or porosity of the soil, the steepness or flatness of the ground, the nature and quantity of the vegetation upon it, the temperature and moisture of the air, the existence of artificial drains, and other circumstances. The following are examples;—

Ground.	Available Rainfall ÷ Total Rainfall.
Steep surfaces of granite, gneiss, and slate,	nearly 1
Moorland and hilly pasture	from ·8 to ·6
Flat cultivated country	from ·5 to ·4
Chalk	0

Deep-seated springs and wells give from ·3 to ·4 of the total rainfall.

Such data as the above may be used in roughly estimating the probable available rainfall of a district; but a much more accurate and satisfactory method is to measure the actual discharge of the streams at the same time that the rain-gauge observations are made, and so to find the actual proportion of available to total rainfall.

The following Table gives the mean annual rainfall in various parts of the world.

TABLE OF RAINFALL. Collected by G. J. Symons.

Country and Station.	Period of Observations.	Latitude.	Mean Annual Fall.
EUROPE.	years.	° ′	ins.
AUSTRIA—Cracow	5	50 4 N	33·1
Prague	47	50 5	15·1
Vienna	10	48 12	19·6
BELGIUM—Brussels	20	50 51	28·6
Ghent	13	51 4	30·6
Louvain	12	50 33	28·6
DENMARK—			
Copenhagen	12	55 41	22·3
FRANCE—Bayonne	10	43 29	56·2
Bordeaux	32	44 50	32·4
Brest	30	48 23	38·8
Dijon	20	47 14	31·1
Lyons	..	45 46	37·0
Marseilles	60	43 17	19·0
Montpelier	51	43 36	30·3
Nice	20	43 43	55·2
Paris	44	48 50	22·9
Pau	12	43 19	37·1
Rouen	10	49 27	33·7
Toulon	..	43 4	19·7
Toulouse	52	43 36	24·9
GREAT BRITAIN—			
England, London	40	51 31	24·0
" Manchester	40	53 29	36·0
" Exeter	40	50 44	33·0
" Lincoln	40	53 15	20·0
Wales, Cardiff	40	51 28	43·0
" Llandudno	40	53 19	30·0
Scotland, Edinburgh	40	55 57	24·0
" Glasgow	40	55 52	39·0
" Aberdeen	40	57 8	31·0
Ireland, Cork	40	51 54	40·0
" Dublin	40	53 23	30·0
" Galway	40	53 15	50·0
HOLLAND—Rotterdam	..	51 55	22·0
ICELAND—Reikiavik	5	64 8	28·0
IONIAN ISLES—Corfu	22	39 37	42·4
ITALY—Florence	8	43 46 N	35·9
Milan	68	45 29 N	38·0
Naples	8	40 52	39·3
Rome	40	41 53	30·9
Turin	4	45 5	38·6
Venice	19	45 25	34·1
MALTA	..	35 54	15·0
NORWAY—Bergen	10	60 24	84·8
Christiania	..	59 54	26·7
EUROPE—*continued*.			
PORTUGAL—	years.	° ′	ins.
Coimbra (in vale of Mondego)	2	40 13	224·0?
Lisbon	20	38 42	23·0
PRUSSIA—Berlin	6	52 30	23·6
Cologne	10	50 55	24·0
Hanover	3	52 24	22·4
Potsdam	10	52 24	20·3
RUSSIA—			
St. Petersburg	14	59 56	16·2
Archangel	1	64 32	14·5
Astrakhan	4	46 24	6·1
Finland, Uleaborg	..	65 0	13·5
SICILY—Palermo	24	38 8	22·8
SPAIN—Madrid	..	40 24	9·0
Oviedo	1	43 22	111·1
SWEDEN—Stockholm	8	59 20	19·7
SWITZERLAND—Geneva	72	46 12	31·8
Great St. Bernard	43	45 50	58·5
Lausanne	8	46 30 N	38·5
ASIA.			
CHINA—Canton	14	23 6 N	69·3
Macao	..	22 24	68·3
Pekin	7	39 54	26·9
INDIA—			
Ceylon, Colombo	..	6 56	91·7
" Kandy	..	7 18	84·0
" Adam's Peak	..	6 50	100·0
Bombay	33	18 56	84·7
Calcutta	20	22 35	66·9
Cherrapongee	..	25 16	610·3
Darjeeling	..	27 3	127·3
Madras	22	13 4	44·6
Mahabuleshwur	15	17 56	254·0
Malabar, Tellicherry	..	11 44	116·0
Palamcotta	5	8 30	21·1
Patna	..	25 40	36·7
Poonah	4	18 30	23·4
MALAY—Pulo Penang	..	5 25	100·5
Singapore	..	1 17	190·0
PERSIA—Lencoran	3	38 44 N	42·8
Ooroomiah	1	37 28	21·5
RUSSIA—Barnaoul	15	53 20	11·8
Nertchinsk	12	51 18	17·5

TABLE OF RAINFALL—*continued.*

Country and Station.	Period of Observations.	Latitude.	Mean Annual Fall.	Country and Station.	Period of Observations.	Latitude.	Mean Annual Fall.
ASIA—*continued.*	years.	° ′	ins.	N. AMERICA—*cont.*	years.	° ′	ins.
RUSSIA—Okhotsk ..	2	59 13	35·2	W. INDIES—Matanzas	1	23 2	55·3
Tiflis	6	41 42	19·3	Grenada	..	12 8	126·0
Tobolsk	2	58 12	23·0	Guadaloupe, Basse-terre	..	16 5	126·9
TURKEY—				Guadaloupe, Matonba	..	16 5	285·8
Palestine, Jerusalem	14	31 47	65·0?	Jamaica, Carnib ..	..	18 3	97·0
	3	31 47	16·3	,, Kingstown	..	17 58	83·0
Smyrna	..	38 26 N	27·6	St. Domingo, Cape Haitien	..	19 43	127·9
AFRICA.				St. Domingo, Tivoli	..	19 0	106·7
ABYSSINIA—Gondar ..	..	12 36 N	37·3	Trinidad	..	10 40	62·9
ALGERIA—Algiers ..	10	36 47	37·0	Virgin Isles, St. Thomas'	..	18 17	60·6
Constantina	..	36 24	30·8	Virgin Isles, Tortola	..	18 27 N	65·1
Mostaganem	1	35 50	22·0	SOUTH AMERICA.			
Oran	2	35 50 N	22·1	BRAZIL—Rio Janeiro ..	..	22 54 S	58·7
ASCENSION	2	8 8 S	11·5	S. Luis de Maranhao	..	3 0 S	276·0
CAPE COLONY—				GUYANA—Cayenne ..	6	4 56 N	138·3
Cape Town	20	33 52 S	24·3	Demerara, George Town	5	6 50	87·9
GUINEA—				Parimaribo	..	6 0	229·2
Christiansborg ..	..	5 30 N	19·2	NEW GRANADA—			
MADEIRA	4	33 30 N	30·9	La Baja	6	7 22	54·1
MAURITIUS—Port Louis	..	20 3 S	35·2	Marmato	15	5 29	90·0
NATAL—Maritzburgh	..	29 36 S	27·6	Santa Fe de Bogota	6	4 36	43·8
ST. HELENA	3	15 55 N	18·8	VENEZUELA—Cumana	..	10 27	7·5
SIERRA LEONE	..	8 30	86·0	Curaçoa	..	12 15 N	26·6
TENERIFFE	2	28 28 N	22·3	AUSTRALIA.			
NORTH AMERICA.				NEW SOUTH WALES—			
BRITISH COLUMBIA—				Bathurst	3	33 24 S	22·7
New Westminster ..	3	49 12 N	54·1	Deniliquin	2	35 32	13·8
CANADA—				Newcastle	3	32 57	55·3
Montreal, St. Martin's	2	45 31	47·3	Port Macquarie ..	12	31 29	70·8
Toronto	16	43 39	31·4	Sydney	6	33 52	46·2
HONDURAS—Belize ..	1	17 29	153·0	NEW ZEALAND—			
MEXICO—Vera Cruz ..	..	19 12	66·1	Auckland	2	36 50	31·2
RUSSIAN AMERICA—				Christchurch	3	43 45	31·7
Sitka	7	57 3	89·9	Nelson	2	41 18	38·4
UNITED STATES—				Taranaki	2	39 3	52·7
Arkansas, Fort Smith	15	35 23	42·1	Wellington	2	41 17	37·8
California, San Francisco	9	37 48	23·4	SOUTH AUSTRALIA—			
Nebraska, Fort Kearny	6	40 38	28·0	Adelaide	6	34·55	19·2
New Mexico, Socorro	2	34 10	7·9	TASMANIA—			
New York, West Point	12	41 23	46·5	Hobart Town	12	42 54	20·3
Ohio, Cincinnati ..	20	39 6	46·9	VICTORIA—Melbourne	6	37 49	30·9
Pennsylvania, Philadelphia	19	39 57	43·6	Port Phillip	11	38 30	29·2
South Carolina, Charlestown ..	15	32 46	48·3	WEST AUSTRALIA—			
Texas, Matamoras ..	6	25 54	35·2	Albany	..	35 0	32·1
WEST INDIES—Antigua	..	17 3	39·5	York	1	31 55 S	25·4
Barbadoes	10	13 12 N	75·0	POLYNESIA.			
,, St. Philip	20	13 13 N	56·1	SOCIETY ISLANDS—			
Cuba, Havannah ..	2	23 9	50·2	Tahiti, Papiete ..	5	17 32 S	45·7

Springs.—Everyone is familiar with the fact that certain porous soils, such as loose sand and gravel, absorb water with rapidity, and that the ground composed of them soon dries up after heavy showers. If a well be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching some lower part of the porous formation where it rests on an impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same manner as we see the salt water filtrate into and fill any hollow which we dig in the sands of the shore at low tide. A spring, then, is the lowest point or lip of an underground reservoir of water in the stratification. A well, therefore, sunk in such strata will most probably furnish, besides the volume of the spring, an additional supply of water.

The transmission of water through a porous medium being so rapid, we may easily understand

why springs are thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, or other permeable substances, while the subjacent are composed of clay or other retentive soils. The only difficulty, indeed, is to explain why the water does not ooze out everywhere along the line of junction of the two formations, so as to form one continuous land-soak, instead of a few springs only, and these oftentimes far distant from each other. The principal cause of such a concentration of the waters at a few points is, first, the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels, and, secondly, the frequency of rents and fissures, which act as natural drains. That the generality of springs owe their supply to the atmosphere is evident from this, that they vary in the different seasons of the year, becoming languid or entirely ceasing to flow after long droughts, and being again replenished after a continuance of rain. Many of them are probably indebted for the constancy and uniformity of their volume to the great extent of the subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in all great lakes, for these are not sensibly affected in their levels by a sudden shower, but are only slightly raised, and their channels of efflux, instead of being swollen suddenly like the bed of a torrent, carry off the surplus water gradually.

Among the causes of the failure of Artesian wells, we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for, when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands to some trough in an opposite direction,—as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs.

The mere distance of hills or mountains need not discourage us from making trials; for the waters which fall on these higher lands readily penetrate to great depths through highly-inclined or vertical strata, or through the fissures of shattered rocks; and after flowing for a great distance, must often reascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. It should be remembered that the course of waters flowing under ground bears but a remote resemblance to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea; whereas, in the other, the water may at one time sink far below the level of the ocean, and afterwards rise again high above it.

Store Reservoirs.—The purpose of a store reservoir is to contain a sufficient quantity of the excess of rainfall in wet seasons, to allow the supply to be kept up uninterruptedly throughout the year. Thus the capacity of such a reservoir will be determined by the available annual rainfall, and the annual service demand. On both these questions much difference of opinion exists, and consequently we find no uniformity in the practice of engineers. Even in cases where the same bases have been adopted in calculating the available rainfall and the average daily consumption, there is a want of uniformity in estimating the storage room required. We learn from Beardmore's Hydraulic Tables that the capacity of existing store reservoirs varies from one-third to one-half the available annual rainfall, and that the quantity stored varies from 120 to 180 days' supply. The longest drought observed in England lasted 105 days, and as such a drought is never likely to be exceeded in duration, it would seem that 120 days' supply would in every case be amply sufficient. But in calculating contingencies, it must be borne in mind that the drought may begin when the reservoir is half empty. Moreover, the loss of water by evaporation in hot, dry weather is very great, a fact that is usually under-estimated. Instances have occurred where a storage of 150 days' supply has proved insufficient. But on the other hand, it should not be forgotten that during a season of drought the supply to the reservoir does not cease altogether; at least, such is not the case until the drought has lasted for a considerable time. If this fact be estimated at its true value, it will be found that, provided there be no extraordinary circumstances to take into account, 120 days' demand will be sufficient. Except at the end of a prolonged dry season, there is, even in the driest weather, a flow of about one-fourth of a cubic foot a second from every 1000 acres of the watershed; and this gives a supply of 130,000 gallons in the twenty-four hours. In the cases alluded to in which a larger storage was found to be insufficient, the demand was probably under-estimated.

In calculating the capacity of a reservoir, there must always be a certain space left below the lowest working level that is not available for storage. The use of this space, or bottom as it is termed, is to collect the sediment from the water. No rule for the volume of the bottom can be deduced from existing examples, for here again we find a total want of uniformity. Some engineers give a depth equal to one-sixth of the total depth of the water at the deepest part of the reservoir; but it is difficult to discover on what basis such a calculation rests. The object being to allow a depth of still water above the bottom for the purpose of preventing sediment from being drawn off, this end would probably be best attained by allowing such a depth that at the lowest working level no portion of the bed at a distance of 3 ft. from the water's edge shall be less than 6 in. from the surface.

When the capacity of the reservoir has been determined, its dimensions will depend mainly on the character of the site. Depth is essential to the purity of the water, for in shallow water the growth of plants is very rapid. Moreover, as evaporation depends upon the extent of surface exposed, the loss from this cause will be less as the depth is increased. For these reasons, a reservoir should always possess considerable depth.

In selecting the site of a reservoir, the chief things to be considered are the elevation, and the configuration of the ground. The elevation must be such that from the lowest water-level there shall be a sufficient fall to provide for the highest point to be supplied and the highest point over

which the water has to be conveyed, and that above the top water-level there shall be a gathering ground of sufficient extent to furnish the requisite quantity of water. The configuration of the ground is a matter of great importance. The site which in this respect is the most suitable for a reservoir is a valley, across the outlet of which an embankment may be thrown, for in such a case only one side is artificial. It is not often, however, that these favourable conditions are to be met with. Very little guidance can be given in this matter; it must be left to the skill and judgment of the engineer to make the best use of the natural features with which he has to deal. When the site and the dimensions have been fixed upon, a plan should be prepared with a sufficient number of contour lines to allow the capacity of the reservoir to be calculated for every foot in depth; for when this is known, a vertical scale fixed in it will at once show the actual contents at any moment. Another important matter connected with the choice of a site is the nature of the soil. It is obvious that unless the stratum forming the bottom and sides of the reservoir be an impervious one, it will not retain the water. Very frequently the stratum forming the surface is permeable, and in such a case it is necessary to make borings to ascertain where an impervious one is to be met with, because at whatever depth this may be situate, the embankment must be carried down to it. It is also requisite to make several borings within the limits of the reservoir, in order to discover any permeable strata that may crop out; for such strata would convey away the water if proper precautions were not taken to prevent it. The engineer should also ascertain where fitting materials may be obtained for the embankment, and especially the puddle-walls.

The selection of the site of the embankment is a matter of the greatest importance, and one that tests the knowledge and ability of the engineer more perhaps than any other connected with reservoir construction. A bad selection may entail enormous labour and expense, and even then lead to failure. Instances might be cited in which the work has been abandoned after a great outlay had been incurred. Too much attention cannot be devoted to an examination of the site previous to commencing operations, and every information bearing directly or indirectly upon the question should be diligently sought after. The figure of the ground must be determined with accuracy by making, not only a longitudinal section along the centre line of the proposed embankment, but several cross-sections taken at suitable points. The former will be a cross-section of the valley, and will show the nature, form, and position of the impervious stratum, which must be unbroken from one side of the valley to the other, and must rise on both sides above the top water-level. To enable these sections to be made, it will be necessary to sink numerous trial shafts, both along the line of the embankment and on each side of it. In no case should these practical tests be omitted, for the appearance of the ground at the surface is very deceptive, and if only one or two borings are made a fault may be missed. Unless the nature of the ground be accurately determined by these means, no reliable estimate of the cost can be made. It is very important that the sinking of the trial shafts should not be suspended as soon as water-tight material is met with, for the stratum may be of insufficient thickness or broken by fissures and faults, in which cases the permeable strata beneath will carry off the water. When such a case occurs, the sinking must be carried on till another and more satisfactory stratum is reached. Also if the outcrop of a permeable stratum has been discovered in the bed of the reservoir, it must be clearly ascertained that the sinking for the foundation of the puddle-wall of the embankment has been carried through such stratum, as otherwise the water would be carried off by it beneath the embankment. In some localities, where the pitch of the strata is high, this latter condition might require the puddle-ditch to be carried down to a very great depth; and in such a case it might be more practicable to remove the permeable material at the outcrop for a few feet in depth, and to fill the excavation with puddle.

The best material for the foundation of a reservoir embankment is clay, and the next compact rock free from fissures. In preparing the foundation, all porous materials, such as sand, gravel, and fissured rock, should be carefully removed, as well as all materials that are not sufficiently strong to carry the weight of the embankment. Before the excavation for the puddle-trench is begun, the thickness of the puddle-wall at the surface of the ground must be determined. As the pressure of the water at the foot of the wall increases with the depth, it is usual to make the thickness depend upon the height. But as it is unnecessary to make this thickness proportionate to the pressure, we find a want of uniformity in the practice of engineers. A batter of 1 in 8 or 1 in 12 on both sides of the wall is the rate of increase commonly adopted; but the thickness of the wall at the top of the embankment varies in existing examples from 3 to 10 ft. It is certain that a puddle-wall 3 ft. thick at the top, and having a batter of 1 in 12, is sufficient to prevent filtration of the water so long as the wall remains in a sound condition; but in so thin a wall there is danger of cracks and fissures being caused by unequal settlement. The extreme thickness of 10 ft. is evidently greatly in excess. A good rule would be to make the top thickness 5 or 6 ft., according to the quality of the puddle, and in every case to give a batter on both sides of 1 in 12. When the thickness of the wall at the surface of the ground has been determined, the puddle-trench may be commenced. Here the usual practice is to make the trench diminish in width downwards, in the same proportion as the puddle-wall diminishes above the surface upwards. There is, however, no sufficient reason for this decrease in thickness below the surface; on the contrary, as the ground on the up-stream side is completely saturated with water, the pressure on the puddle increases with the depth of the trench, and theoretically therefore the thickness of the wall should increase to the bottom of the trench. But such a design would lead to great practical difficulties, for the ground would not stand if undermined for the trench in that way, however strong the timbering might be. A similar objection lies against the common practice of making the width of the trench diminish in depth. It is difficult to dress the sides of a deep trench to a steep batter, and still more difficult to timber it effectively. And if we take into account the extra labour involved in working in the narrow space towards the bottom of the trench, we must conclude that the plan of sinking the trench with perpendicular sides, and thus keeping the puddle of the same thickness from the surface of the ground to the bottom of the trench, is the most economical that can be adopted.

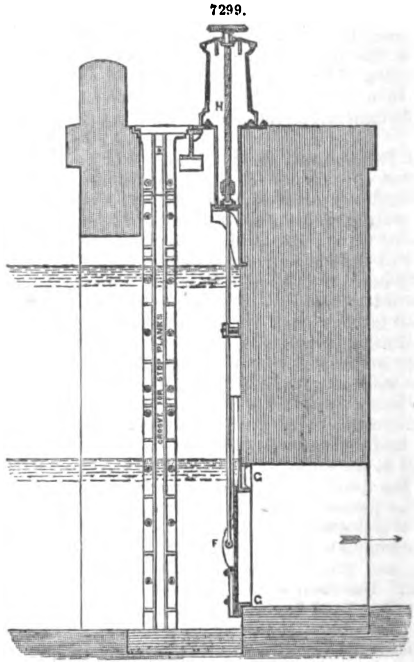
Care must be taken to prevent injury from springs rising under the base of the embankment. Fissures through which water issues may be calked with oakum, or, if large, plugged with wooden or iron plugs. If water rises from the bottom of the trench, it will be necessary to sink below it. When the rock is very wet, strong concrete should be used to fill up the bottom portion of the trench.

The puddle used should consist of strong, tough clay, soft, miry clay being quite unsuitable. Great care should be taken that it make a perfectly water-tight joint with the bottom of the trench. To ensure this when the foundation is solid rock, the latter is commonly cut into grooves or steps running parallel with the centre line of the embankment. When the trench has been filled up to the surface of the ground, the embankment may be commenced. The construction of these embankments has been fully described in our article on Rivers, to which we refer our readers. It is necessary to remark, however, that when a puddle-wall is used, it should be supported on both sides by a wall of the same thickness of strong and carefully-selected materials. All soft material should be removed from the site of the embankment, and if the site be on sidelong ground, it should be carefully benched and levelled. The water slope is usually 1 to 3, and is protected by stone pitching in the way described in the article referred to above. Sometimes a wall of masonry is used instead of an embankment. Such walls have been described under Dams and Retaining Walls.

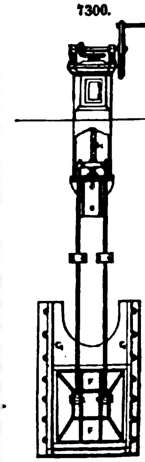
Previous to the failure of the Dale Dyke at Sheffield in 1864, the outlet was generally by a culvert under the embankment. This culvert contained a pipe or pipes which passed through a water-tight stopping in the culvert, and it was of sufficient dimensions to admit of the access of workmen. The down-stream end of the culvert was open, and often provided with wing-walls, which sustained the thrust of part of the outer slope of the embankment; the up-stream end was usually closed with water-tight masonry, through which the lowest or scouring outlet-pipe passed. In numerous instances a tower was built on the inner end of the culvert, near the foot of the water-slope, to contain outlet-pipes for drawing water from different levels, with valves and mechanism for opening and shutting them. These valves were usually only short pipes extending through the walls of the tower, and furnished with sluices. When so situate, the tower is reached from the top of the embankment by a light foot-bridge. Sometimes the tower was imbedded in the embankment, and was then called a valve-pit. If the reservoir was for a town water-supply, the culvert contained two outlet-pipes, one at the lowest working level, and the other on a level with the bottom of the reservoir. The latter pipe is intended for scouring purposes only. This outlet by culvert is to be found in many of the existing reservoirs. It is, however, open to the grave objection of weakening the embankment. It is usually placed at the point where the height of the bank is greatest, and as it crosses the puddle-trench, which is filled in with a soft, yielding material, that sinks away from it in time from settlement, it is liable to fracture. Even when an arch is thrown over the trench to give support to the culvert, the puddle is weakened by being pierced, and the settlement of the whole embankment is seriously interfered with.

Since the accident above referred to, the culvert has been abandoned in favour of a tunnel driven round one end of the embankment through solid ground, or even beneath the bank. When the tunnel passes round the end, a valve-shaft is constructed in a line with the puddle-trench from the tunnel to the surface of the ground. The tunnel at the bottom of the shaft is in some cases filled up with a plug or stopping of water-tight masonry, the chamber at the junction of the tunnel and the shaft being made somewhat larger than the rest of the tunnel to allow the plugging to be well keyed into the sides. The outlet-pipes and valves are inserted in this stopping. There are two outlet-pipes, as in the culvert, and it has been recommended that each should be provided with two valves, one of which should consist of a pipe extending to the top of the shaft, and furnished with grooves capable of receiving an ordinary sluice or paddle. This paddle could thus be lowered into the outlet-pipe in front of the other valve, which might be of the ordinary spindle kind, and in the event of an accident to the latter, the paddle could be lowered, and the valve taken out and repaired, the supply in the meantime being continued through the other pipe. The portion of the tunnel between the valves and the reservoir should be lined with brick to prevent detached pieces of rock from dropping and being carried to the valves.

7299.



7300.



7301.

One of the inlet-sluices used at the Glasgow Water-works is shown in Figs. 7299 to 7301. The water is first admitted from the lock into a basin 55 ft. long by 40 ft. wide inside, through three cast-iron sluices each 4 ft. square. Across the middle of the basin is fixed a line of strainers, to keep fish and floating objects from passing into the aqueduct from the lock. The cast-iron sluice-plate F is faced with brass and works against brass faces on the cast-iron frame G, which is securely let into the masonry and is furnished with guides to keep the sluice F in its place. The sluice is raised and lowered by means of the iron screw H working in a brass nut, the screw being turned by a crank and bevel-wheels at top.

The overflow or waste weir is essential to the safety of every reservoir. It is a weir at such a level and of such a length as to be capable of discharging from the reservoir the greatest flood discharge of the streams which flow into it. Knowing this discharge, and allowing a maximum depth of say 6 in. over the weir, the length of the latter may be easily calculated. The weir should be built of ashlar or square hammer-dressed masonry. Instead of a weir, what is known as a waste pit is in some cases used; this is a tower rising through or near the embankment to the top water-level, into which the waste water falls, and is carried away by a culvert at the bottom. But as such a tower can seldom have a sufficient extent of overfall, the safety it affords is questionable. The water that flows over the waste weir is conducted away to the natural water-course by a by-wash or channel. This by-wash may be much narrower than the weir, as the water may flow through it with an increased depth. In all cases the by-wash should be cut round the end of the embankment, and not brought over the embankment itself. Sometimes it is cut to take the flood waters without allowing them to pass into the reservoir, and this plan is preferable for several reasons. Usually the waste weir is segmental in form, and a fall of 1 or 2 ft. is allowed on the down-stream side. To prevent too great a velocity in the channel by which the water is conveyed to the natural course, the channel should be carried along level for some distance from the reservoir. Some engineers break the floor occasionally by steps. When steps are used, the fall should not be more than 9 in., and the tread of the step should be equal to at least twice the fall. Near the reservoir, a layer of concrete should be placed under the bottom of the by-wash. Further information on these matters will be found under the head of Weirs, in the article on Rivers.

The following Table, by N. Beardmore, furnishes reliable data for estimating the storage room required;—

Water Supply and Drainage Areas

Required for various Amounts of Population, at different Rates of Supply, with a Guide to the Cubic Contents of Reservoirs, where that method of Supply is adopted.

Discharge Required.		Number of Population.			Gathering Ground Required.		Reservoir Required.
Cubic Feet a minute.	Gallons a day.	At 30 Gallons a Head a day.	At 40 Gallons a Head a day.	At 50 Gallons a Head a day.	With Stream delivering 8 cub. ft. to each sq. mile.	With 12 in. of Rain a year, or 53 cub. ft. a minute to each sq. mile.	Holding Water for 4 Months, at 53 cub. ft. a minute.
cub. ft.	millions.	No.	No.	No.	sq. miles.	sq. miles.	cub. ft. millions.
27·8	·25	8,333	6,250	5,000	3·48	·52	4·88
55·7	·50	16,666	12,500	10,600	6·96	1·05	9·76
83·5	·75	25,000	18,750	15,000	16·44	1·57	14·65
111·4	1·00	33,333	25,000	20,000	13·93	2·10	19·53
139·2	1·25	41,666	31,250	25,000	17·41	2·63	24·42
167·1	1·50	50,000	37,500	30,000	20·89	3·15	29·30
195·0	**1·75**	**58,333**	**43,750**	**35,000**	**24·37**	**3·68**	**34·18**
222·8	2·00	66,666	50,000	40,000	27·85	4·21	39·07
250·7	2·25	75,000	56,250	45,000	31·33	4·73	43·95
278·5	2·50	83,333	62,500	50,000	34·82	5·26	48·84
334·3	3·00	100,000	75,000	60,000	41·78	6·31	58·60
390·0	3·50	116,666	87,500	70,000	48·75	7·36	68·37
445·7	4·00	133,333	100,000	80,000	55·71	8·41	78·14
557·1	**5·00**	**166,666**	**125,000**	**100,000**	**69·64**	**10·52**	**97·68**
668·6	6·00	200,000	150,000	120,000	83·57	12·62	117·21
780·0	7·00	233,333	175,000	140,000	97·50	14·74	136·75
891·4	8·00	266,666	200,000	160,000	111·43	16·82	156·28
1,002·8	9·00	300,000	225,000	180,000	123·11	18·92	175·82
1,114·3	10·00	333,333	250,000	200,000	139·29	21·02	195·36
2,228·6	20·00	666,666	500,000	400,000	278·58	42·05	390·72
3,343·0	**30·00**	**1,000,000**	**750,000**	**600,000**	**417·87**	**63·07**	**586·08**
4,457·3	40·00	1,333,333	1,000,000	800,000	557·16	84·10	781·44
5,571·6	50·00	1,666,666	1,250,000	1,000,000	696·45	105·13	976·80
6,686·0	60·00	2,000,000	1,500,000	1,200,000	835·74	126·15	1,171·16
7,800·3	70·00	2,333,333	1,750,000	1,400,000	975·04	147·18	1,367·52
8,914·6	80·00	2,666,666	2,000,000	1,600,000	1,114·33	168·21	1,562·88
10,029·0	90·00	3,000,000	2,250,000	1,800,000	1,253·62	189·23	1,758·24
11,143·3	**100·00**	**3,333,333**	**2,500,000**	**2,000,000**	**1,392·91**	**210·25**	**1,953·60**

Of the Inclination and Section to be given to Feeders and Conduits.—When a certain quantity of water has to be conveyed by means of feeders and conduits, the first question that presents itself is, the determination of the declivity and the dimensions of the wetted section. With respect to the declivity to be given to the work, it frequently happens that local circumstances allow it to be varied within certain limits; and in that case, the engineer must decide what is best suited to the existing conditions. Some writers maintain that the velocity of the water in a feeder should never be less than 1 ft. a second to preserve its wholesomeness. But though we do not deny that in this respect a considerable velocity is an advantage, we think it would be unwise to make great sacrifices to obtain it. A stream having a velocity of only 9 in. a second would travel twelve miles a day; and if the feeder were of that length, or even twice or three times that length, the passage of the water in the stream would correspond to a storage of one, two, or three days in the reservoir; and as it is kept completely stagnant in reservoirs a much longer time than that, we fail to see how it could become corrupted in so short a space of time. From this point of view, a much lower velocity than 1 ft. a second may be allowed, especially in conduits of masonry. Rankine, however, places the limits to the velocity at 4 ft. and 1 ft. a second, because above 4 ft. small stones will be carried along; and below 1 ft., the conduit will silt up. It may be mentioned here that the *Aqueduc de Ceinture* at Paris, which distributes the water of the Ourcq, has a perfectly level bed, the water flowing in it in virtue of the declivity established at its surface. The most substantial advantage of the declivity is to reduce the section of the water-channel, and consequently the expense. But this advantage is very small for slight variations of declivity. Thus, for an increase of declivity of $\frac{1}{10}$, the section is diminished by only $\frac{4}{100}$; and for certain forms of section this diminution would not lessen the expense at all. It may be added, too, that when the water brought by a conduit has to be distributed by means of force mains, the diameter of the mains must be increased in proportion to the insufficiency of the head; and thus the saving effected by increasing the declivity of the conduits may be lost in the increased expense of the mains. As the course of a water-channel must depend in a great measure on the natural features of the ground, the question of the declivity cannot be submitted to algebraical laws. It is an eminently complex question, like that of the gradients of a road, or of railways. The engineer cannot, any more than he can in these cases, confine himself to limits of declivity, or to a uniform declivity. Throughout the course of the channel, the declivity and the section must vary with the inequalities of the ground; but, of course, as every variation of these quantities is in itself an objectionable feature, there must be a sufficient reason for making it. It must be kept in view that the problem to be solved is, how to convey a given quantity of water from one point to another with the least possible expense. And the solution of this problem will depend in a great measure upon local circumstances.

Artificial water-channels are of two kinds, those the sides of which are of earth, and those which are constructed of masonry; the latter are more usually called conduits or aqueducts.

Artificial Water-channels without Masonry.—Water-channels without masonry are only suited for conveying large quantities of water. It is indispensable that they should have a sufficiently large section, to avoid any interruption of the flow by accumulations of aquatic vegetation, deposits, or accidental slips in the banks. They require frequent cleansing; and a certain amount of water is lost by evaporation and filtration. It is also requisite to retain a path along their banks to enable them to be kept in a proper state. The water is liable, too, to get heated by the rays of the sun when its volume is small. But if a large quantity of water has to be conveyed, these disadvantages sink into insignificance, compared with the economy of this system of construction. When, however, local circumstances and the wants to be supplied demand only a very small section, it will be in nearly all cases best to have recourse to a channel of masonry, or even to an underground conduit, which will effectually protect the water from the accidents to which we have alluded. We do not exclude unbricked water-channels from a project of water-supply; but they should be used only for large quantities of water. It must be remembered, too, that when the channel is in a deep cutting, the sides have a large extent of surface; and this, in some soils, entails considerable expense.

Water-channels of this nature are more particularly connected with navigable works, of which they are nearly always an essential accessory. We may here caution the engineer against the method of calculating the loss of water by filtration by the square yard of surface, as is done in the case of navigable canals. This method, which we believe false in principle, does not lead to any sensible error when canals are compared with each other; because these canals have in general sensibly equal wetted sections and water surfaces; but it might lead to grave miscalculations if applied to water-courses of small dimensions, such as those suitable for a town water-supply. The permeability of the soil will have a much greater influence than the dimensions of the water surface. The loss by filtration in canals ought not, therefore, to be considered proportional to their breadth. Hence it follows that, for narrow water-channels, the loss will be relatively much greater; and as the cost of puddling or walling is evidently proportional to the breadth, there will be more inducement in the case of the narrow channel to undertake these works.

Stone or Brick Conduits.—Many works have been written on the stability of structures in stone; arches of various forms, with their abutments and piers, have been submitted to calculation; and sufficiently accurate rules have been laid down to serve as guides in these matters to engineers. But the case of these structures being at a greater or less depth beneath the surface of the ground has been almost wholly neglected. The stability of retaining walls is only a particular case of the thrust of earth. The numerous underground ways which the construction of canals and railways necessitates at the present day offer an application at least as important of this theory. It would be beyond the scope of this article, however, to supply this want; we shall therefore consider merely the question of conduits, which, from their nature, are of small dimensions.

These conduits always consist of a bed and two side walls, covered with flagstones when narrow, and with an arch when of a certain breadth. If we suppose such a structure as this erected on the surface of the ground, all its parts must have certain dimensions, in order that they may not give

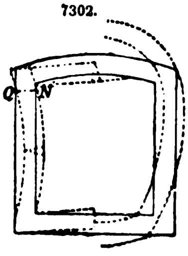
way either inwards or outwards. These dimensions would still be given to the parts, if the arch, instead of being above ground, were in the middle of an artificial embankment, because the earth of which such an embankment is composed is liable to slip away sufficiently to let the arch down between the walls. It is for this reason that in making roads or railways the same dimensions are given to the arches and abutments of the small bridges situate in an embankment as if these structures were situate above ground. The saving that might be effected by utilizing the thrust of the earth is here not taken into account. This saving would, moreover, be small, as the works themselves are of small extent. But when sewers and conduits several miles in length have to be constructed, the importance of giving to the masonry only that thickness which is strictly necessary, and of choosing a suitable form of section, will be seen at once.

In general, in every piece of tunnelling there is a minimum necessary free space. In the case of a railway or a canal, there must be room enough for two trains or two barges to pass each other in a certain position with respect to the axis; in the case of a sewer or a conduit, we have a wetted section with sufficient space for the passage of a man, either upright or in a stooping posture, either dry-footed or in the water. In other words, we have a polygon of a given kind and size to be enveloped in an intrados curve, subject to no other condition than that of giving the minimum cost of construction. Sometimes the polygon is not so fully determined as in the cases just cited. In a sewer, for example, where the flow requires a sectional area of 3 sq. yds., and the work of cleansing and repairing a minimum height of 2 yds., it is evident that this double condition may be satisfied by rectangles of very different heights and breadths. It is therefore requisite to know which are, in general, the most economical forms.

The cost of constructing a subterranean passage consists of two parts, that of the masonry, and that of the excavation necessary to obtain this masonry. We will consider each of these separately. A tunnel cannot give way outwards. We are not speaking of the exceptional case of loose earth, or earth liable to be loosened by the action of water; these are rare circumstances, demanding special precautions. But generally the soil met with is stable, and only slightly compressible, so that the surface of the extrados of the tunnel is subject throughout to a variable pressure perpendicular to its surface. If the walls of the tunnel are in equilibrio, by reason of the dimensions given to the several parts of the extrados, it is clear that its outer surface will be subject to no other pressure than that which was exerted upon the mass of earth which previously occupied the same space, for, on account of the hollow of the tunnel, its weight will be sensibly equal to that of that mass, and a giving way can only occur inwards. Suppose, now, the perimeter of the tunnel to have such a thickness that its outward thrust is exactly equal to the outer pressure of the earth; in this case equilibrium will be established, though the structure, considered alone, is not in such a condition. But it will be readily seen that this equality of action and reaction is necessarily produced, unless the earth is very compressible and the radii of curvature of the intrados very large.

Let us consider one of the most unfavourable cases, namely, that of a tunnel composed of two walls, a segmental arch with a very long radius, and a rectilinear floor, Fig. 7302. This mode of construction evidently brings a very considerable thrust against the top of the walls. If the tunnel be cut through rock, the stone N, which constitutes an abutment, will not be forced back sufficiently far to let the arch down before finding a reaction equal to the thrust Q; but if the ground were of a more yielding nature, it would very likely happen that the springings would not meet, as they were being thrust back, with a sufficient reaction from the earth in time to prevent the straightened arch from slipping down between the walls. We may add, too, that this accident would be in nearly all cases caused by the displacement of the soil rather than by its compression. The soil, pressed back by the thrust on the springings, will give rise to pressures above and below; the latter will press the walls inwards, and give them a convex form inside. But virgin soils are only in a very small degree compressible, and the settling down of structures is due more to the displacing of the soil upon which they are erected than to its compression. There are therefore two means of preventing the fall of the arch, to buttress the walls, and to give a greater rise to the arch. It is evident that we shall then necessarily find equilibrium without increasing the thickness of the masonry. By means of a greater rise we shall diminish the horizontal thrust, and at the same time extend the limit which the joint of rupture may reach without causing the fall or deformation of the arch. By buttressing the walls, we shall prevent the springings from being forced apart.

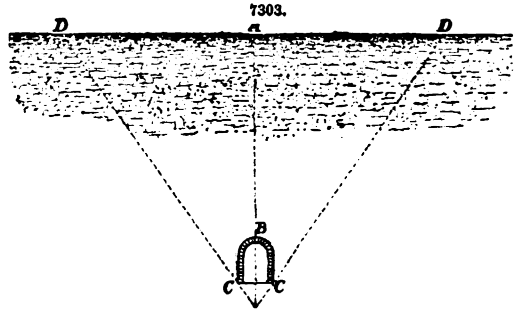
7302.



Hence it follows that by giving the inner section of a tunnel a concave form throughout its perimeter, the condition of equilibrium may always be attained with very thin masonry. In order to submit these forms to a vigorous calculation, it would be necessary to know the pressures exerted upon the surface of a solid buried in the earth. But this is a very complicated problem, and one that could be solved only by means of a great number of hypotheses on the friction and cohesion of soils, and the elasticity of the body compressed; that is, data which have not yet their expression in figures, and which consequently are of little practical interest. We shall merely remark that the pressure upon the extrados of a tunnel depends but little on its depth beneath the surface; a careful consideration will show that the upper soil tending to slide upon the slopes of greatest thrust, C D and C′ D′, Fig. 7303, supports itself upon the vertical plane A B passing through the axis of the tunnel, so that the portion B C may, even for a certain height, varying with the degree of cohesion of the soil, stand without support. It may therefore be admitted generally that the pressure due to the thrust is very little; the truth of this is evinced by the natural caverns found in mountains, and in those which are often dug, without support of any kind, in soils having a certain consistency. We are speaking now of the natural thrust which would exist if the extrados of the tunnel were in inflexible monolith. But if the masonry thrusts outwards, it is evident that the soil will press inwards with equal energy, a reaction that must be the result of a certain com-

pression. Now, if the soil is perfectly sustained, a sensible alteration in the form of the masonry can never result from this compression. We may remark, however, that when the tunnel is constructed in a trench or cutting which is afterwards filled in, the soil resting upon the arch not having much cohesion with the sides of the cutting, there must be a greater pressure upon the top than when the arch is built underground. But this vertical pressure only serves to tighten the joints in the arch, and to increase the stability of the side walls.

7303.



From these considerations we deduce this consequence, namely, that subterranean structures ought to be constructed according to other principles than those of ordinary structures of masonry; that by taking advantage of the reaction of the soil against any outward thrust, by choosing rational forms, and by varying suitably the radius of curvature of the intrados curve, we may considerably reduce the thickness of the masonry in works of this nature. They ought to be pipes of a nearly constant thickness in the perimeter of the section, which thickness should vary only with the diameter, that is, within certain limits of section, as the cost of masonry is sensibly proportional to the perimeter of the curve of the intrados. The cost of excavation does not follow exactly the same law; but as in ordinary cases it is only a small fraction of the total cost, we may, as an approximation, generalize the principles, especially when we are drawing only general conclusions.

When, therefore, a determined section is required, a slightly elliptical form is to be chosen. An exaggeration of the height would cause extra expense, except in the case of a very deep trench.

Of Different Kinds of Culverts.—Culverts may be divided into three classes, according to their dimensions; those which furnish a passage for the water only, those which are sufficiently high to allow a man to walk up them, and those which are provided with pipes for the conveyance of the water, so that a man may pass through dry-footed. We shall briefly consider each of these systems, and the circumstances that may render one or the other of them preferable in a given case.

Culverts having dimensions sufficient only to afford a passage for the water are evidently the cheapest. If a wetted section of 12 in. by 6 in. or 8 in. is sufficient for the discharge, if the nature of the water is such that no cleansing is required either in consequence of impurities or calcareous deposits, and if the course is not situate in a deep cutting, this system will offer the greatest advantages. In case of accident, by means of man-holes situate at certain intervals, the locality of an injury may be proved to be between two of them; then by digging midway between them, and again midway between this point and the man-hole, the exact locality may be discovered. But small leakages at several points might take a long time to discover, and would entail great expense. A coating of cement has peeled off and blocked up the passage; small cracks, which singly are unimportant, but which, being repeated throughout a long distance, are collectively the cause of a great loss of water, such things may occasion a long search and a heavy outlay for repairs. These culverts, however, appear very suitable for the conveyance of small quantities of water.

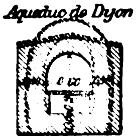
We stated above that the pressure at each point of the perimeter is unknown, but it is easy to see that it must be greater in the vertical than in the horizontal direction. The curve of equilibrium must therefore affect the form of an ellipse, greatly elongated or approaching the form of a circle, according as the soil possesses greater or less cohesion.

These little culverts may be constructed of stone, beton, or cement; or stoneware pipes may be substituted for them. The choice between these several modes depends on circumstances and local resources. The thickness to be given to the walls is so little as to elude calculation. In such small sections, a giving way inwards can hardly occur; the only accident to be feared is a sinking of the soil,—occasioned, not by the weight of the structure, but by filtrations escaping from it. It would therefore be dangerous to construct these culverts upon an embankment. As to virgin soils, it must be left to the engineer to determine on the spot what special precautions are to be taken. We may remark, however, that, in most cases, it will be sufficient to ram the bottom of the trench. The proportions of the wetted section may be varied to satisfy given conditions. In many parts, materials may be found very suitable for making slabs or flagstones to form the top, which will dispense with arching; in such a case, the breadth will be limited to the dimensions required to utilize these materials. If it is desirable to keep out the water of the soil passed through, the joints of these stones must be cemented. A rounded form for the bottom of these culverts is favourable to the velocity of the water, and facilitates cleansing when necessary. A coating, or layer of cement, laid on thicker at the angles, has been found very suitable for giving this form.

When, in consequence of the exigencies of levelling, a culvert has to be placed at a great depth beneath the surface, the foregoing system loses its advantages in several ways. Suppose, for example, that, for an ordinary trench from 3 ft. to 6 ft. deep, the cost of the small culvert is 10*s.*; it will increase to 20*s.* or 30*s.* in that portion for which a deep cutting is necessary. In such parts it is requisite not merely to deepen the trench, but to widen, and plank, and strut it. Hence an enormous increase of cost, which will be the same for the small as for the large culvert; so that the relative cheapness will no longer compensate the defects pointed out, especially as the position of the culvert will greatly aggravate them. For instance, it will be almost impossible to ascertain the locality of a leakage at such a depth. Therefore, in a deep excavation, the culvert must be sufficiently large to be accessible on the inside. The question

then is, What dimensions are strictly necessary to give this advantage? The example of the culvert at Dijon, Fig. 7304, constructed by the famous hydraulic engineer, Darcy, proves that 2 ft. 11½ in. in height, by 1 ft. 11½ in. in breadth, is quite sufficient to allow a man to pass up it without excessive fatigue. It must be borne in mind, that it is not a case demanding a daily or even a monthly examination; all that is required is for a man now and then to pass up with a torch to examine every part; and by making use of the man-holes, he may rest as often as he likes. The mean term taken by Darcy appears to us, therefore, perfectly rational. In virtue of these dimensions, the culvert at Dijon possesses, for the security of the distribution, the same advantages as those of the largest dimensions; its defects are a mere matter of service, for which the public have not to suffer; a question of paying a small sum yearly to the man whose duty it is to pass through the culvert occasionally in water-tight boots. To render this culvert capable of being easily traversed by a man upright, the side walls would have had to be 3 ft. higher; and this, from the dimensions adopted, would have required an additional cube of brickwork, equal to 28·25 ft., and, with the earthwork, involved an expenditure of at least 8s. a yard, say 5600*l.* for the whole length of nearly 7⅜ miles. To effect such a saving as this, an occasional inconvenience will be cheerfully borne. We must remark, however, that, had the egg-shaped section been adopted, a greater height would have been given at the same cost, by diminishing the thickness of the side walls, Fig. 7304, which would have greatly facilitated the passage of the inspector.

7304.



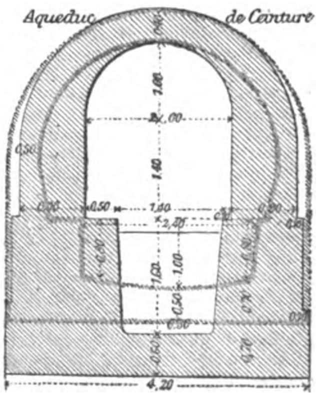
Another advantage of this kind of culvert is its capability of conveying a variable quantity of water, whilst the small ones would be quickly destroyed if the under-pressure of the water were to burst up the arch, or lift off the top stone-slabs. This defect is remedied by means of escape-holes left at convenient places. Stoneware pipes, being capable of withstanding a certain pressure, are more suitable than small culverts for the conveyance of variable quantities of water.

The essential dimension of this kind of culvert is its height; and it is evident that by increasing this we render access to it more easy; the only question, therefore, is that of cost. There are certain advantages, too, which are more or less important, according to local circumstances. In case of repairs, the workman has but little room to use his tools, or to transport his materials. If the water leaves a deposit, and the culvert requires cleansing occasionally, its dimensions must be increased. In many of the old culverts there is a raised footway on one or both sides, by means of which inspection, repairs, and cleansing may be executed without standing in the water. This is no doubt an advantage; but whether the additional cost is compensated by the convenience afforded, is open to question.

Critical Examination of Two Culverts.—We will complete these general considerations by making a critical examination of two culverts recently constructed in the interior of the city of Paris.

A glance at the section represented in Fig. 7305 shows that the engineer has wholly left out of consideration the subterranean position of the structures, for the brickwork has a thickness more than sufficient for equilibrium if erected above ground. In this order of ideas, the offsets, allowing them to be necessary to the stability of the structure, would yet be a mistake, for by raising the side walls vertically from the perpendicular of the last offset, the breadth of the water-passage and footway might be increased by 7·8 in. without diminishing in the least degree the mean thickness of the brickwork; or if this additional breadth of the water and footways were deemed superfluous, the offsets might have been suppressed, and the same thickness of brickwork retained, which would have reduced the breadth of the trench. For we must not lose sight of the fact that an offset, though it may be only a few inches high, necessitates the same width of trench to surface, thus occasioning great additional expense. We think, therefore, it may be laid down as a principle, that a culvert built in a trench should never have offsets.

7305.

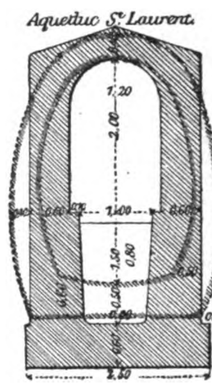


If, now, we examine the form of the water-way, we shall see that the breadth and depth are not in the ratio requisite for a maximum velocity of the water. This, however, would be a small defect if the section adopted were in the minimum conditions of cost. But we see at once that in consequence of the enormous thickness of the side walls, especially on the side of the footway, there is great advantage to be gained by increasing the breadth of the water-way and diminishing its height. The two side walls have together a thickness of 8·53 ft., whilst that of the arch and floor is only 3·28 ft.; consequently, by increasing the breadth of the water-way by ·328 ft., and diminishing its height by the same quantity, we gain about 5·5 cub. ft. of brickwork, without diminishing the section. The proportion is therefore bad in all respects. If we increase the breadth of the water-way to 7·87 ft., reduce its mean height to 2·95 ft., and then raise above the footway a more rational profile than the existing one, we shall effect a saving of about 135 cub. ft. of brickwork and 85 cub. ft. of excavation, representing a sum of about 4*l.* a yard, or 16,000*l.* for the whole work, while retaining the raised footway and the ledge on the inside intended to support a flooring of planks in case of repairs. The modified profile shown in Fig. 7305 in dotted lines gives at once much more air and room in the portion above the water, and a sufficient breadth to allow the passage of a good-sized boat, with a diminution of weight upon the foundations and of height of water upon the floor, that is, with fewer chances of filtrations. If we were to enter further into the examination of this culvert, and discuss the utility of the ledge mentioned above, and that of the raised footway, which might be suppressed altogether, or replaced

by a plank supported upon cast-iron brackets, we should arrive at still more economical forms. We will merely add, however, that the culvert, being both reservoir and culvert, that is, the water in it being alternately in motion and at rest, the section which we propose for the water-way ought to have been deepened towards the end to counterbalance the effect of the descent. But we are considering it here only as a type of culvert designed to convey a large quantity of water.

The section of the Saint Laurent culvert, Fig. 7306, appears to us at least as defective as the one we have been examining; the same corrections are to be made. By reducing the height of the water-way by 2·39 ft., giving a curved form to the side walls, and doing away with the offset, we should get a form as strong as the present, more economical by one-third of the brickwork, and of suitable dimensions to allow the passage of a boat, or of a man in water-tight boots, if it were considered undesirable to have planks supported on brackets. These sections therefore ought not, in our opinion, to be taken as examples to be imitated.

7306.

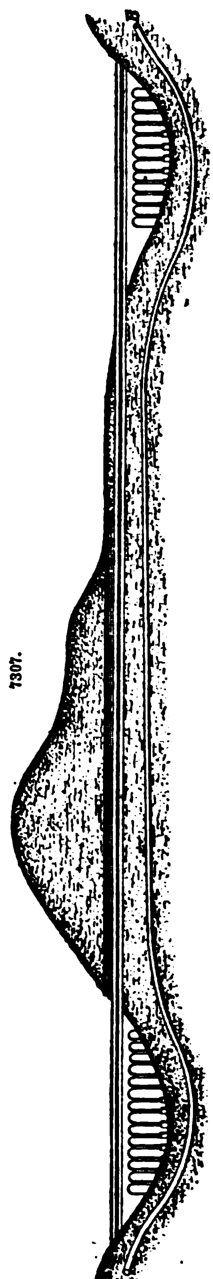


We shall not pursue this critical examination further, our only object in entering upon it at all being to show the great importance of carefully considering the form of section to be given to a culvert. It is not possible, as in the case of pipes, to give typical forms which are always to be imitated; the engineer must in every case be guided by local circumstances, the material at his disposal, and a thorough understanding of his subject. The considerations into which we have entered are not intended to remove the necessity for a careful study of the question, but to make that necessity more strongly felt.

Culverts to contain Pipes.—Most of the foregoing reflections are applicable to culverts intended to receive pipes. We shall consider later the question whether pipes should be placed in culverts at all; and though, in our opinion, it is not in general advisable, especially for a small water-supply, to construct special culverts for the mains, it is none the less true that when these culverts may at the same time serve for other purposes, it becomes expedient to place the pipes in them. A sewer, for instance, may be rendered suitable for this purpose by slightly increasing its width, and this increase of width may be effected at a small cost.

Culverts may contain one or several pipes; but, in our opinion, they ought never to contain more than two, unless different kinds and pressures of water have to be conveyed. Multiplying the number of pipes greatly increases the cost, and cannot be justified from any point of view. When a culvert is to serve at the same time as a sewer, the mains are raised upon a brick footway in order that they may not be immersed in the sewage, which immersion would conceal any escape, and render repairs difficult. To make the joints more readily accessible, the pipes rest at intervals upon brick supports. Instead of a brick footway, which takes up a portion of the section of the sewer, iron consoles are frequently employed; these possess the additional advantage of greatly facilitating the first placing and subsequent repairs of the pipes. At the same cost, this system is certainly preferable; it will be for the engineer to compare the cost of each, according to the diameter of the pipes and local circumstances.

7307.



Of the Choice to be made between Conduits and Pipes.—It remains for us now to consider the question of knowing in what cases recourse should be had to force-mains and to free culverts, or, as they are often called, conduits.

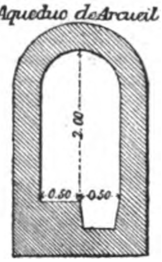
If we consider the problem of conveying water in an abstract way, both systems are applicable in every case. A line A B, Fig. 7307, being given, we may adopt any form of section for a conduit having a sufficient surface to convey the given quantity of water; the conduit or culvert will be constructed in a trench or in a tunnel when the water-line is below ground, and upon a wall or upon arches when above ground. As to the pipe, it may always be substituted for the culvert by placing it below the line of head, and giving it a section about $\frac{1}{10}$ greater than that of the culvert. Thus, *mathematically*, one system may in every case be substituted for the other; but, *economically*, the question is changed, and each system finds its place according to local circumstances.

When the water-line, or line of head, is below ground, the culvert possesses over the force-pipe advantages varying with the system adopted, and with the quantity of water conveyed. Suppose a small culvert having, for example, a wetted section 12 in. × 6 in.; if we wish to substitute a pipe for this it must have a diameter of about $9\frac{3}{4}$ in. This will cost about 20*s*. the yard run, whilst the little culvert will hardly cost 8*s*. If the culvert is a little larger, and its useful section doubled by making the side walls 6 in. higher, the cost will be increased by not more than two or three shillings a yard, whilst the diameter of the pipe would be increased to $13\frac{3}{4}$ in., and the cost to about 28*s*. The saving would

thus be about 18*s*. the yard. But if for so small a quantity of water a culvert were constructed large enough for a man to enter, this saving would vanish, and there would be an excess of expenditure instead, for it would be difficult to construct a culvert for less than 30*s*. On entering this system the relative economy diminishes, because the wetted section is only a small fraction of the whole. Suppose in a culvert of this kind, having a breadth of 1·97 ft., the depth of water to be 1·30 ft., the wetted section will be 2·5 ft., and we might substitute for this culvert a 2-ft. pipe. Thus it will be seen that if the culvert cost 33*s*., the saving is only a third of the total expense. It will be greater if we suppose a greater height of water in the culvert; but in that case it will be difficult to enter it while in use; such would be a culvert of the first kind. As to culverts like that of Arcueil, Fig. 7308, which convey only a small quantity of water, and may be passed through dry-footed by men in the upright posture, they are much more expensive than pipes. The difference diminishes, it is true, with the quantity of water, but we doubt if it can ever become nothing. Thus the first of the two culverts at Paris, which we have already critically examined, cost 30*l*. the yard run, and it does not exceed in efficiency three 39-in. pipes, which would not have cost half that sum.

7308.

Aqueduc de Arcueil



The comparison we have made is incomplete in many respects, for it does not take account of many elements that may derive great importance from the conditions in which the engineer finds himself placed. We will remark, in the first place, in favour of the culvert, especially that kind which is large enough to be accessible, that it offers much more security for an uninterrupted service. Probably to obtain the same degree of security from pipes, they would have to be doubled, which, as we have said, greatly increases the cost, in the ratio of 1 to 1·56. Also, if the water forms calcareous or other deposits, the work of cleansing can be performed much more easily and at much less expense. But this advantage is of small importance, for water charged with such a quantity of carbonate of lime ought not to be used.

The considerations in favour of pipes are of another kind. We have supposed them laid down in the track of the conduit; but that supposition is too unfavourable, since a force-pipe is in no wise restricted to follow the developments of the line of head over the ground. To convey water from Uzès to Nîmes, the Romans were obliged to construct an aqueduct 31 miles long, though the towns are situate only 12½ miles apart. We see that a force-pipe would have been only half that length; hence two savings, that of length and that of diameter, resulting from the increase of declivity to the yard. The diameter might, indeed, have been reduced in the ratio of 1 to 0·87. Again, for the reason that the conduit must of necessity follow the line of head, and all the windings of the soil, it is often requisite to pass through valuable lands, the owners of which have to be paid compensation, whilst the force-pipe, which is subject to no other condition than that of being situate below the line of head, may be placed in the streets, in the roads, or other public properties, where no compensation is required. This liberty of choosing a course enables supplies to be given on the way, and thus the utility of the service is increased.

The course or track of a conduit is subject to more rigorous conditions than that of roads and railways, as it only admits of nearly insensible declivities, and never of counter declivities; if, therefore, it were absolutely necessary to follow the line of the soil, it would assume an excessive length. To abridge this length, rising ground is often cut through and valleys crossed by aqueduct-bridges. When the line of head is in a deep cutting, preference should in general be given to the culvert rather than the pipe; the latter would require the same trench and probably the same expense as the culvert, but being situate so far from the surface, it might fracture or the joints give way, without the accident being perceived, for the water not being able to reach the surface, could find escape only in a lateral direction. And the search for defects would be so difficult and expensive that it would be necessary probably to place the pipe in a culvert where it would be accessible at all times. It will therefore be much more simple to put the water itself into the culvert, and so save the cost of the pipe.

General Principles on the Choice of Conduits.—We must conclude, then, that the problem of the economical conveyance of water is eminently complex; and that the engineer must call to his aid, according to local circumstances, all the various systems, each of which has its proper place, but which cannot be determined by any precise rules; he may, however, be guided by the following general considerations;—

Canals are suited for the conveyance of large quantities of water through a level district.

The aqueduct is suited to moderate quantities when the level of the supply is reached by tunnelling.

Pipes are best suited for the conveyance of small quantities of water from great heights.

Aqueduct-bridges are only admissible for the conveyance of large quantities of water, and when the supply is not obtained from a great height.

Siphons should only be constructed in order to carry the supply across a stream.

It is only by a complete and detailed study that he will be able to arrive at a knowledge of the systems best suited to each particular case, and these will often have to be modified according to the resources which are at his disposal.

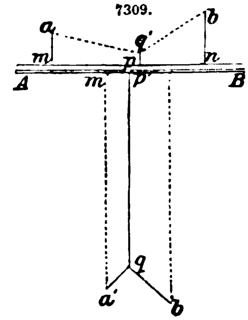
Hitherto we have been occupied in determining the sections, inclinations, and so on, which must be given to a conduit in order that it may furnish a certain quantity of water; this, as has been seen, is always an easy question to solve by analytical formulæ. But the distribution of water presents another question much more complex and interesting; that is, to determine the course of the conduits which will give the result sought with the least possible outlay.

Distribution of the Pipes.—In a previous article on Pipes we entered in detail into the questions relating to the manufacture, the quality, and the requisite diameters of iron pipes for a town water-supply, and we described the most approved modes of laying them, pointing out at the same

time the influence of contour of section, or position, of the pipes with respect to the horizontal. It would therefore be superfluous to introduce those questions into the present article. There yet remains, however, one other question relating to the laying of pipes that we have not considered, but which is of great importance, namely, the course of the mains, or distribution of the system of pipes. This matter is frequently made subordinate to inferior considerations. But the engineer who aims at economy and designs his plan intelligently will make it one of the objects most deserving his attention. By carefully estimating the quantity of water to be delivered at a certain point, and adapting the diameter of the pipe thereto, a considerable saving of cost may be effected. But a much larger saving will result from a good distribution of the mains. Indeed, there is hardly a limit to the economy that may be realized by a skilful distribution, nor to the expenditure to which an unskilful one may lead.

Of course, it is impossible to do more than lay down general principles; for what is applicable to one locality is impracticable in another. The necessity of laying the mains along the streets greatly limits the choice of relative positions, and leaves only a few routes open to the engineer. The choice is, however, less limited than it appears to be at first sight, a fact anyone may convince himself of by a careful study of any town map. But general principles will be of great service to guide the engineer in making this choice; for though he will seldom or never be able to follow the lines which theory requires, if he knows what these theoretical lines are, he will be in a position to approximate to them in practice as closely as circumstances will allow; and in such a case, however wide the approximation may be, he will have the satisfaction of knowing that the distribution he has designed is the best that the nature of the locality rendered possible.

7309.



As an illustration of the degree of economy to be realized by a due attention to the question under consideration, we will take a very simple example. Suppose it be required to deliver a certain quantity of water, say 200 gallons a minute, at the point *a*, Fig. 7309, and 100 gallons a minute at the point *b*, from a principal main A B. It is obvious that the most economical way of accomplishing this is to lay the pipes *a m*, *b n*. But if the points to be supplied were situate at a greater distance from the main, as *a' b'*, it would be far more economical to lay the secondary main *p q*, and to reach the given points by branches *q a'*, *q b'*. This example is almost self-evident; but cases will arise in practice where a careful calculation will be necessary to determine the question. There will, of course, be other conditions to take into account, among which the character of the ground will be the most important.

An important fact to be borne in mind in designing a distribution is, that the cost of conveying a determinate quantity of water, as a cubic foot, through pipes, decreases as the total quantity increases. Consequently there will always be an advantage in concentrating the masses of water to be conveyed, instead of dividing them among a number of smaller mains. The cost of the pipes through which the water is conveyed does not increase as the quantity of water, but only as the $\frac{2}{5}$ power of that quantity. Thus if the cost of conveying 100 gallons be A, the cost of 200 gallons will be $2^{\frac{2}{5}} A = 1 \cdot 32 A$, and that of 300 gallons will be $3^{\frac{2}{5}} A = 1 \cdot 55 A$. That is, if 100 gallons can be conveyed for 1*l.*, three times that quantity can be conveyed for 1*l.* 11*s.*; and so on in the same proportion.

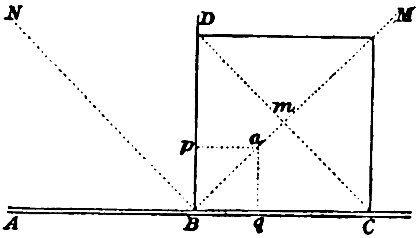
Another question demanding attention is the intersection of branches by the mains, or of secondary by the principal mains. The position of the intersecting main should be towards that end of the branch at which the supply is attended with the greater difficulties, either by reason of the difference of level or of the quantity of water to be delivered. When the two ends are sensibly on the same level, the length of the branch should be divided proportionally to the squares of the discharge. If, for example, the delivery at one end of the branch is 100 gallons and at the other end 200 gallons a minute, the point of intersection will be situate towards the latter end of the branch at $\frac{1}{4}$ its total length from it. This condition will, however, usually require modification, as it would lead to a too circuitous route for the principal main, and so occasion additional cost in the latter. The best theoretical course will be that which without deviating from the straight line passes nearest to the points of intersection determined in the foregoing manner.

From the preceding general principles, we may deduce a typical distribution which shall serve as a guide in every case that may occur in practice. In this typical case the ground is supposed to be sensibly horizontal, of the same character throughout the district, and wholly free from obstructions. Local considerations are thus completely eliminated.

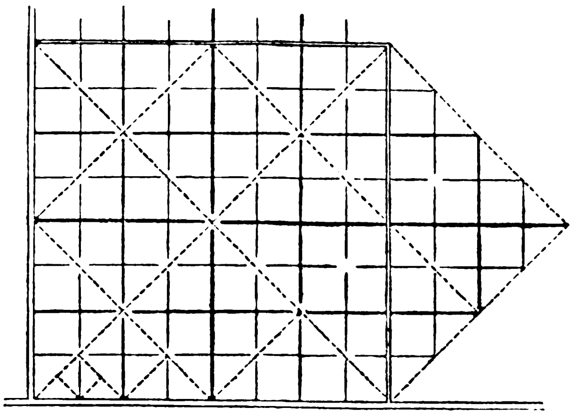
It is evident, from what we have stated above, that this district should be divided into two symmetrical portions by a principal main. We shall suppose the diameter of this main, as well as that of all the others, constant; for when we have solved the problem according to this hypothesis, it will be a simple matter to vary the diameters in accordance with the quantities to be delivered. Thus the question is reduced to that of distributing the water upon one side only of a main considered as an inexhaustible reservoir. Evidently the distributing pipes must be supplied from mains perpendicular to the principal main; what we have to determine is their positions, lengths, and diameters. For greater simplicity and clearness, we will consider one of these mains B D, Fig. 7310, separately. A moment's reflection will show that the limits of the area which should be supplied from this main will be given by the lines B M, B N bisecting the right angles at B which B D makes with the principal main; for according as a point is situate to the right or to the left of the bisecting line, it will be nearer the principal or the branch main. The branches from B D and B C, as *a q* and *a p*, should therefore never extend beyond the line B M, because such an extension would involve a waste of pipe. Hence it follows that upon the line A B C there should be no other

branch of the same importance as B D, that is, of the same diameter, until we reach a distance from B equal to B D, or in other words, until B C = B D. The area of this new branch will be similarly limited by the bisecting line C D, this area being C *m* M, as that of D B is B *m* D, and that of B C is B *m* C. If these three isosceles rectangular triangles are so large as to make it necessary to have

7310.



7311.



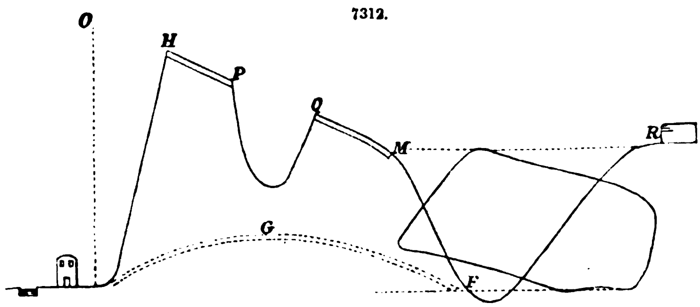
other branches, it is obvious that they should divide the bases B D, B C, and C M into two equal parts; for if they do not occupy that position the cost of the secondary branches will be increased, as we have already demonstrated. If this reasoning be continued throughout the district, we shall obtain the typical distribution sought, which distribution is represented in Fig. 7311. In this diagram the importance of the several lines of pipe is shown by graduating the thickness of the lines, the thinnest lines representing the pipes that supply the smallest areas. These areas, which are shown by dotted lines in the diagram, are squares constructed upon the pipes as diagonals, and they increase by geometrical progression, the ratio of which is 4. Hence it may be shown, that if the diameter of one series of pipes be *d*, that of the next larger series will be 1·75 *d*. Also it may be seen from the diagram that the length of one series of pipes is always double that of the preceding series, as it has to connect all the other series.

A knowledge of the general principles which we have been discussing, and which are illustrated in this typical distribution, will enable the engineer to design his system in the most economical way compatible with the conditions imposed on him by the circumstances of a given case.

It is evidently impossible to foresee all the cases which may arise in practice, and to apply to them the general principles which we have just explained; but we can, at least, facilitate the research by a few examples, showing the advantages and inconveniences of the various means which may be adopted.

Let us suppose the water brought and raised to a certain point O, Fig. 7312, which we will call the point of distribution; the level of this point will, of course, rule the height of the service-pipes. For engines forcing the water directly into the ascending pipe, this point should be considered as being situate at the height which would be given by a manometer placed upon the pipe. The point of distribution may be situate either within the boundary of the district to be supplied, or outside it; it will evidently be sufficient to examine the latter case, which will in its application include the former; as when the point of distribution is situate outside the district to be supplied, the first thing to be done is to carry it inside by means of an aqueduct or conduit.

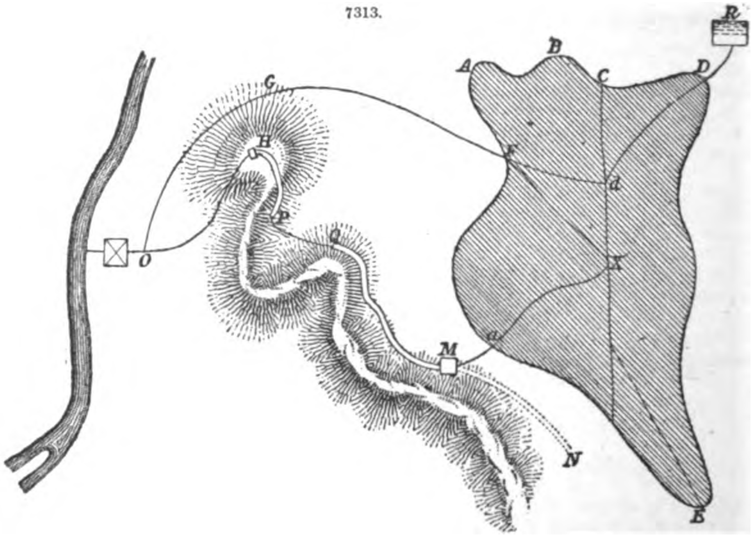
7312.



Let A B C D E F, Figs. 7312, 7313, be a polygon enclosing all the points to be supplied, and O a point on the outside, from which the water must descend to all these points. The water raised by an engine may be conducted by an aqueduct, when there is situate near the engine a hill

running in the direction of the district to be supplied. We must then make the ascending pipe discharge at such a height on the summit of the hill as will allow the aqueduct to have sufficient fall.

7313.



Determination of the Diameter of the Ascending Column.—Whether we adopt this latter arrangement, or conduct the pipe as far as the boundary of the district, there is always a first pipe, the diameter of which is arbitrary. In practice, whatever may be its dimensions, we can always obtain from it the head necessary for the discharge of a given quantity of water, by means of a more powerful engine and a larger consumption of coal. Thus, if we had to raise 3 cub. ft. of water a second a height of 165 ft. by means of a steam-engine, and if the diameter of 16 in. gives a loss of head of 35 ft., the problem will evidently be solved by an engine of 65 horse-power, the cost of which can easily be calculated; and it would be the same for a pipe of any diameter, as, for instance, one of 12 in. giving rise to a loss of head of $35 \left(\frac{16}{12}\right)^{\frac{5}{8}} = 41 \cdot 8$ ft., will require an engine of 71 horse-power, with a corresponding consumption of coal. The question to be determined is, Will the saving effected in the rising main compensate for the extra cost of the engine? In a word, in every question of this nature, the object sought is to find the diameter which will give the minimum of expenditure.

Limit of the Aqueduct at the Boundaries of the Distribution.—As we have already said, the water, on leaving the engine, may be conducted directly to the boundary of the district to be supplied, either by a pipe or an aqueduct. If the district is suited to the combination, the aqueduct may be prolonged to the point where the force-main commences to present advantages. But it is evident that the aqueduct can only be carried over the boundary-line of the district on an embankment, as it must of necessity be above the surface which it has to supply. We shall therefore be obliged to arrest this work at a certain point M, Fig. 7313, near to the boundary, and from there start the force-main. The nature of the district will sometimes admit of the aqueduct being prolonged parallel to the boundary, in such a manner that most of the service-pipes can start directly from it. But before adopting this course we must carefully examine the expense to which it will lead. In fact, the development M N of the aqueduct, and the length of the branch-pipes outside the boundary, will be altogether lost for intermediate service; and it is rarely that we cannot obtain a more advantageous arrangement by starting directly from M with a force-main, for this pipe, distributing the water to right and left, will allow the branches to decrease in length and diameter.

Necessity and Position of Distributing Reservoirs.—It is hardly possible for a distribution of water to be carried on without a reservoir; for the consumption is variable, whilst the supply is constant. The water brought by natural courses, or raised by hydraulic machinery, is constant during the twenty-four hours; whilst the consumption in general goes on only during twelve hours; and during these twelve hours the consumption is not regular; so that, even with steam-pumping machinery, we are obliged to have a reservoir in order to prevent waste of water, the supply of which, at certain moments, exceeds the consumption. Besides this, a reservoir allows of the machinery being stopped for repairs, without interfering with the service. It is, then, almost indispensable; and the only question to be decided is its situation and capacity.

If the reservoir were placed at the head of the aqueduct towards H, Fig. 7313, the dimensions of the aqueduct should be such that it will discharge, not the product a second of the engine or spring, but the maximum consumption a second. But this consideration would often greatly increase the cost of the aqueduct; and more than this, any accident or repairs among the network of service-pipes would interrupt the service. If the reservoir were placed towards M, its position would be better. The aqueduct, reduced to a minimum section, and consequently to a minimum cost, may be, according to the capacity of the reservoir, closed for a greater or shorter time, without interrupting the service; but as the pipe M X d D R from the reservoir must be of sufficient diameter to discharge the maximum consumption, any repairs at X would stop the service.

If, on the contrary, the reservoir were placed at R, the end of the principal conduit, whatever

accident might happen, it would only cause a suspension of the service between the nearest neighbouring stop-cocks. Besides this, as the pipe M X *d* D R is fed from both sides during the time of the greatest consumption, its diameter may generally be much smaller than in the preceding example. The extreme end of the principal pipe, which traverses the boundary, is then the position which best satisfies the conditions of a good distribution; but several circumstances will often interfere to cause us to prefer another situation. The cost of the reservoir, which, as we have already seen, varies considerably, according to the nature of the surface of the district, is one of the most important. If, for example, the level at R, sensibly below M, only allows of the construction of a reservoir to carry on the distribution during the time that the direct service is interrupted, we should, in that case, only erect a reservoir to take the surplus water during the time that the consumption is at its lowest. It should be borne in mind, when making comparison between the various systems of distribution which may be adopted in any particular case, that the principal reservoir should be placed at a sufficient height to command all the orifices of discharge; and that it is advantageous to place it at the end of the main, which starts from the origin of the supply, and traverses the boundary of the district.

Concerning the capacity of the reservoir, it cannot be too large; for the larger it is, the longer the time during which repairs may be carried on without interrupting the service; its capacity will be determined by the facilities which we have for its construction, and the chances of interruption to which the supply is liable; and we have to determine upon a minimum. The same may also be said of the height and the depth; the overflow cannot be too high, nor the bottom too low. The height will be limited, either by the level of the source or the power of the engine, and the depth must be such that it will still be able to supply the highest orifices when the water has descended nearly to the bottom.

Instead of one reservoir, we might have several. Thus, one might be placed at M, another at N, and another at C; in these two latter positions they would have the advantage of increasing the power of the conduits at the ends of which they were placed. It is well in all cases to reserve to ourselves the power of adding fresh reservoirs to the system, according as necessity shall call for them.

The considerations which we have just been explaining apply with equal force to the case where the water is brought from the source O by means of a force-pipe O F G. But then we shall have to consider if it will not be better to divide this conduit into two pipes of equal diameter, so that in case of repairs the service may not be interrupted. Bearing in mind that one of the effects of this arrangement will be an increase of ·45 in the cost of the rising main, we shall have to determine whether the advantages of the system will be a sufficient compensation for this increase.

Purification of Water.—For this section we are entirely indebted to the writings of Ernest Theophron Chapman. Chapman observes that waters contaminated with animal and vegetable matters are purified in nature by the gradual oxidation of their organic matter, aided by subsidence, and, in some cases, by filtration through porous strata. The processes of evaporation and condensation which give rise to rain are also natural methods of purification.

Water is purified artificially by distillation, filtration, and by formation of a precipitate in the water.

Distillation is seldom resorted to for drinking purposes. It is employed at sea, and we believe that on the coast of Chili sea-water is regularly distilled for domestic use. It is, however, not sufficiently used to interest us here.

Filtration is the most common method of purifying water. If a water contains solid particles of a given magnitude, and we pass that water through a wire gauze, the meshes of which are of smaller diameter than the particles, we shall, of course, separate the particles, and unless either the gauze or the particles are elastic, the rate at which the operation is conducted will have no effect on the result. But in filtration, as ordinarily conducted, speed affects the result to a very great extent. In filtering through beds of sand, we may roughly say that the effect of the filtration will be almost inversely as the speed at which the filtration is effected.

If a bottle full of slightly turbid water be laid upon its side, and allowed to stand for twenty-four hours, and then examined, it will be found that the sediment has not only deposited itself on those parts of the glass to which gravitation has carried it, but that, though thickest at the bottom, it has spread itself much higher up, and in many cases is even to be found adhering to the top part of the glass. This circumstance has doubtless much to do with filtration.

There is, however, another consideration which will perhaps be most easily explained by an example. When softening water by Clark's process, we obtain a precipitate of finely-divided carbonate of lime. If this operation be conducted in large glass vessels, we can watch this process of depositing the precipitate. If we do so, we shall observe that the first sign of clearing takes place at the top, a layer of quite clear water making its appearance, and gradually extending downwards. If we ask how this water has become clear, the only answer that can be made is, that the precipitate has moved down to the layer of water beneath it, and thereby rendered that layer thick, for had the precipitate not descended into it, it would, like the top layer, have become clear. In the same way, this second layer, by its depositing, renders that beneath it turbid. If such a vessel of water took six hours to clear, we should expect that by dividing it into six layers by means of five diaphragms, equidistant from each other and from the top and bottom of the water, that the water would clear in one-sixth the time, or one hour. On making the experiment, this is found to be the case. To test this matter more fully, what may be called a subsidence filter was constructed. It consisted of a wooden box 12 in. square and 20 in. deep, containing 24 plates of sheet zinc, ⅞ in. apart. Each plate had six holes punched in it, 1 in. in diameter. The holes were near to the side, and had their edges turned up a little; the plates were so arranged that the holes were not opposite each other. A small tap came from just below the lowest plate. Another box like this, but without plates, was also constructed. Both boxes were charged with freshly-softened water, containing chalk suspended in it. The water took about eight hours to clear in the

box without the plates, and was quite clear in the one with the plates at the end of twenty-five minutes. This box of plates was next used as a filter, by sending a slow stream of water charged with suspended chalk through it. About 11 gallons an hour of quite clear water could be drawn off. If the speed was increased much beyond this the water was no longer clear. To render the analogy between this filter acting entirely by subsidence and the common sand filter quite plain, the box without the plates had a piece of coarse wire-gauze stretched across it just above the tap. It was then filled with slate chips, and water containing chalk in suspension, as before, filtered through it. The action of this filter was exactly the same as that of the plate filter, except that more water could be passed through it in an hour without turbidity. If, however, more than about 15 gallons an hour were passed through it, the water was slightly turbid, and if the quantity was increased to 20 gallons, it was quite so. Some experiments, substituting very coarse sand for the slates, gave analogous results.

Now, the analogy between the last experiments and the subsidence filter is clear; and we may safely draw the inference that a portion of the work performed by a sand filter is due to subsidence within the filter itself, the particles of sand serving as plates. This is almost proved by the fact, that we can force much of the matter removed by such a filter through it, by slightly increasing the pressure of water, which would not be the case if the filter acted as a strainer.

The common process of filtration through sand is therefore an operation comprising three distinct methods of purification:—Straining; removal of matters by adhesion to the sand; subsidence within the interstices of the filter itself.

The first method will vary with the size of the apertures through which the water passes; the second, with the amount of surface in the filtering medium in relation to the amount of water; the third will vary with the speed at which the water travels, and with the size of the aperture through which it passes.

Some filtering media are said not only to remove organic matter, but to destroy it. They are said to do this by causing the organic matter to combine with the oxygen contained in the water, and thus convert it into innocuous compounds. Foremost amongst the compounds said to possess this property stands animal charcoal. Beyond all doubt, animal charcoal has a wonderful power of freeing water from organic matter, and it does to some extent oxidize the organic matter; but whether to a greater extent than can be accounted for by the oxidation always going on in water exposed to the air, is a question which admits of much doubt.

The only process of purification by precipitation requiring detailed remark is Clark's softening process. Waters to which this method of purification is adapted are such as contain carbonate of lime retained in solution by excess of carbonic acid. The process consists of adding lime to such waters until the excess of carbonic acid is neutralized; when this has taken place both the lime added and that in solution are precipitated as carbonate, a minute quantity remaining in solution, as carbonate of lime is not absolutely insoluble in water. By this process not only is the water softened, but a very large proportion of the organic matter contained in it is removed, and if the water be coloured, the colouring matter is also entirely or in very great part removed.

The following examples will indicate to what extent the organic matter is removed by this process;—

PARTS PER 1,000,000.

		Free Ammonia.	Albuminoid Ammonia.			Free Ammonia.	Albuminoid Ammonia.
I.	Before Clark's process	0·01	0·05	III.	Before Clark's process	0·015	0·22
	After „ „	0·01	0·02		After „ „	0·020	0·07
II.	Before Clark's process	0·025	0·22	IV.	Before Clark's process	0·195	0·12
	After „ „	0·030	0·08		After „ „	0·15	0·05

It is to be observed that the organic matter removed can be proved to be present in the chalk precipitated.

The process presents so many advantages, and is so simple, that we are surprised not to see it in general use, and naturally expect to find on investigation that it has some great drawback. This, however, does not appear to be the case.

The only other methods of purification by precipitation which have been adopted to any extent are the addition of alum to the water, and the addition of a persalt of iron. In both cases the result is the same, a precipitate is formed which carries down with it a very large proportion of the organic matter, sometimes as much as three-fourths.

Filter Beds.—Two systems of filtration are in use for filtering water on a large scale, the artificial filter, and the natural filter.

The artificial filter bed was designed to get rapidly rid of that very light portion of the sediment carried by river waters, which takes some time, a fortnight or more, to subside under ordinary circumstances. This clayey discoloration, though trifling in weight, renders the water very objectionable in appearance and in its application to any of the arts or manufactures. That portion of the sediment which, from its greater weight, subsides rapidly, say within twenty-four hours, can be more economically got rid of in subsiding reservoirs. The successful use of the filter bed presupposes the preparation of the water in a subsiding reservoir. Wherever the attempt has been made to use filter beds without that preliminary aid, they have either failed altogether, or rendered the water but partially clarified. In some places, the large valley reservoirs required for compensation and flood storage perform for the filter beds the functions of a subsiding reservoir.

The materials used for filtration on a large scale are sand, gravel, and broken stone or shingle, the depth of the whole varying from 5 to 6½ ft.; a layer of shells has sometimes been used, placed within the stratum of gravel, but this is not found essential, and is now generally omitted.

It will be convenient to consider here the most appropriate size for a filter bed before giving the arrangement and thickness of its materials. The sizes in practice will be found to be very variable,

and seemingly to have followed no regular standard. The first filter beds at Chelsea proved inconveniently large, and have since in practice been divided. The new filter beds at Stoke Newington, London, the filter beds at Liverpool, and those now under construction at Dublin, are fair specimens of modern practice, as applied to large cities. For small cities it is found convenient to make the dimensions proportionally smaller. The areas of these are 45,000, 30,000, and 22,550 sq. ft. each, respectively. Their forms are rectangular, 300 × 150, 300 × 100, and 205 × 110. At Stoke Newington, with a delivery of 12,000,000 imperial gallons daily, there are five filter beds in use now, and two projected, making seven in all when complete. In Liverpool there are six, for a delivery of 9,000,000 to 12,000,000 imperial gallons. At Dublin, for an assumed delivery of 12,000,000 imperial gallons, there are seven filter beds in process of construction.

Each filter bed, at short intervals varying with the condition of the water, must have the deposit which accumulates on the surface of the sand cleaned off or removed, and while any one is undergoing this cleansing process, the other remaining filters must be competent to deliver the required supply without overstraining their functions. If, then, there are six filters, five of them must be competent to the full duties of the service, and if eight filters, seven of them must be competent to this duty, on the supposition always that not more than one filter will at any time be off duty. Should the circumstances in effect render two unserviceable, the remainder must have area enough to meet the requirements of the case.

We see, then, that the smaller the filter beds—with the condition, however, that not more than one shall be off duty at a time—the smaller will be the total area of filtering surface required for the particular duty. The materials available for construction, and their cost, will also measurably influence the dimensions to be adopted, and it must always be borne in mind that although there may be but one filter off duty, it will frequently happen that another is nearly unserviceable. It is therefore found best to give a liberal area of filtering surface, to be prepared for all the contingencies of the service.

The bottom of the filter bed is prepared to suit the circumstances of its position. It must be made practically water-tight. This is sometimes ensured by laying concrete on the bottom, but quite as often by a layer of hard clay puddle 18 to 24 in. thick, over which a flooring of brick is laid; where the ground is more than usually bad, both the clay and the concrete may be used with advantage; when concrete is used the brick paving is not essential. Upon this flooring a central drain, running lengthwise, is laid, with which are connected on either side small tubular drains of 6 to 9 in. diameter, prepared for this purpose, the sides being pierced with holes to facilitate the entrance of the water. These side drains are laid nearly at right angles to the central drain, and from 8 to 12 ft. apart. The central drain is frequently a double drain, performing two offices—the lower part, which is covered, gathering the filtered water, and the upper part, which is open, delivering the unfiltered water upon the sand, when refilling a filter bed immediately after cleansing, and in use then only for that special purpose. This central drain is sometimes of brick, and sometimes of stone covered with stone flagging, the side walls of the lowest 12 in. of the drain being in either case laid dry; the water-way for this size of filter should not be less than 30 in. wide by 15 in. of height.

A little reflection will show that the lateral drains can hardly be placed too close together, for it is desirable that the filtered water should flow to the collecting drains with as slow a velocity as possible; and the further these drains are apart, the greater must be the amount of water running through each drain.

This drainage skeleton rests on the base of the filter bed, and becomes the means provided to collect the filtered water and deliver it to the outer passages or wells. Upon the flooring of the filter beds, and covering the gathering drains as well as filling up the intervening spaces, a layer of broken stones is laid, large shingle or quarry spauls. The stone should not be larger than will pass through a 4-in. ring, nor less than will pass through a 2-in. ring, and they must be clean and free from earth or quarry rubbish.

The shingle so called is obtained in England from coarse gravel or beach deposits, and is screened to the size wanted.

This layer of broken stone must be 24 in. thick to cover efficiently the pipe drains. Upon this layer of stone properly levelled off, from 18 to 24 in. of gravel is laid. This gravel is usually screened into two or three sizes, the larger of walnut size, the next of the size of a hazel nut, and the third between that and pea size. The largest size lies upon the broken stone, the smallest size at the top, the layers 6 in. thick each. Over this gravel there is laid not less than 30 in. of fine sharp sand, screened to ensure the requisite degree of fineness and uniformity. The lower 12 in. may be a little coarser than the upper stratum of 18 in., but it is important that the two layers should be of uniform fineness and quality throughout, otherwise there will be danger of the water passing through more rapidly at one point than another. The whole depth of these materials amounts to *five feet eight inches.*

From the ends of the pipe drains, as well as from the end of the central drain, small cast-iron pipes of 4 in. diameter, rise to the surface of the ground to enable the air to escape while the water is being first let on upon the filter bed.

In England the sides are usually paved with brick or stone to slopes of from 1 to 1 to 2 to 1. In North Germany the side walls have to be vertical on account of ice, and the depth of the water over the filter beds is not less than 4 ft.

In the worst stages of the English rivers a filter bed has to be cleansed once a week, rarely oftener. The stuff, whether sediment or otherwise, intercepted by the filter, is found collected on the surface of the sand; in the process of its removal, a thin paring of sand is necessarily taken with it, not exceeding from ½ in. to ¾ in. in thickness. The impurities carried by the water are not found to have penetrated the sand. The paring of sand is usually cleansed and laid aside for future use, except when fresh sand can be procured at less cost than the washing of the old sand. The thickness of the sand bed is allowed to be reduced by these repeated parings from 8 to 12 in. before it is renewed.

The original thickness of 30 in. of sand becomes then but 18 or 22 in. before it is replaced and brought up to the original lines. The renewal is usually made once in six months, sometimes but once a year, as the convenience of the service may permit.

At each cleansing of the filter bed the sand is loosened by forks for some 6 to 8 in. in depth, and afterwards raked smoothly over.

The sand is liable to pack close if the cleansing is too long delayed. In such case the weight of the water is felt upon the sand; in the usual state of the filter it is not so felt.

The filter bed is usually filled with water from above by flowing it slowly upon the sand either from one point in connection with an overflow drain, or from several points on the side of the filter. It would be safer and more convenient as regards getting rid of the air, to fill it from below by means of the drains there; but if this were done with the uncleaned water it would distribute its impurities all through the filter. The filtered water may, however, by suitable arrangements, be made available for this service. When the filter has been once filled it is not necessary to empty it entirely at each cleansing of its surface.

The lowering of the water 12 to 18 in. below that surface will afterwards be sufficient to admit of the workmen removing the crust of sediment collected upon it.

To ensure the perfect cleansing of the water by the filters as well as to prevent any disarrangement of the materials of which they are composed, the velocity of movement of the water must be very slow. The average rate is ½ gallon a minute for each square yard of sand surface, which is equal to 3⅓ gallons an hour for each square foot of sand area of the filter bed. James Simpson, who may be said to be the originator of the method of filtering now in such general use in England, is of opinion that the filtering surface should be predicated on a rate of 72 gallons a day for each square foot of sand, which is equal to 3 gallons an hour a square foot.

When the flow of water through the system of filters during the twenty-four hours cannot be made uniform, that is to say, when, as is sometimes the case (in the absence of an intermediate clear water basin), it varies with the consumption, being greater during the day hours than during the night hours, the combined area of the filter beds in that case should be made to meet the maximum or daylight consumption of the service an hour.

The filtered water from each filter bed should be delivered into a small well, whence it escapes into the proper conduit, and is carried either to a common clear water basin, or directly to the pumps. The sluices at this well can be so arranged, by operating downwards instead of upwards, as to adjust the head of water actually in action upon the filter bed. When the filter is clean, 9 in. of head will produce the required flow through the filtering material; according as the sediment becomes deposited on its surface, this head has to be increased to 2 or 2½ ft., varying a little with the character of the sand. If the head be allowed to exceed 3 ft., it is because the surface is being rapidly closed; the weight of the water comes then into play upon the sand, induces the packing already referred to, and leads to the labour of loosening up the material during the process of cleansing. Sometimes when this amount of head is exceeded, the pressure leads the water to break through at points where some slight difference in the material gives it opportunity. It will then flow through in veins, damaging the filter bed; but such overstraining of the filters is rare.

Natural Filters.—Bordering upon all rivers there are found at intervals narrow plains of gravel or sand brought down and deposited there by the river under the varying positions of its channel way. When these beds of gravel extend to a depth below the bottom of the neighbouring stream, they will always be found saturated with water mainly derived from that stream, and however turbid the water of the river, this underground flow will always be found clear, provided that we tap it at a reasonable distance from the channel way.

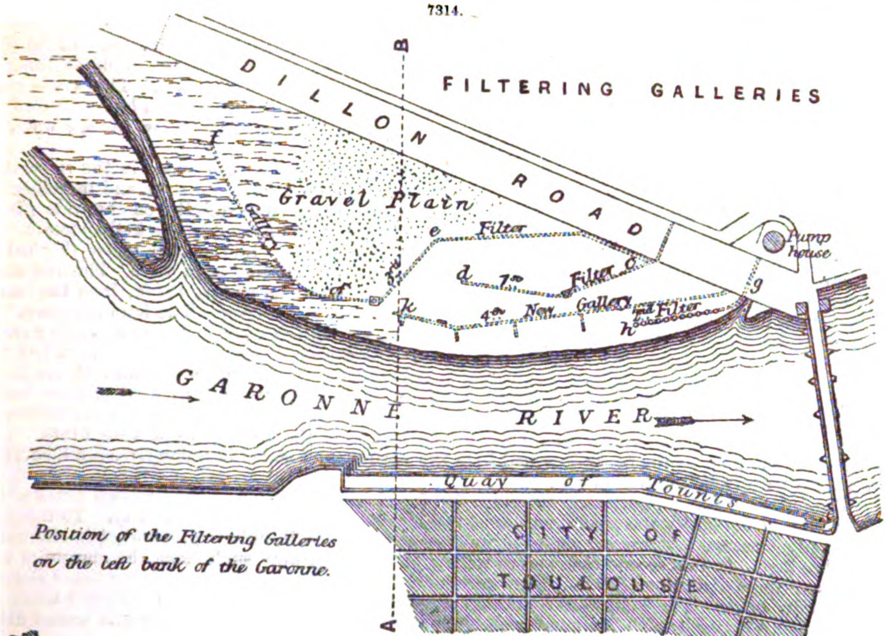
Covered galleries are carried through these beds of gravel at depths sufficiently below the channel of the neighbouring stream to ensure a supply of water within the gallery during the lowest stages of its water. The water in these gravel beds rises and falls with the height of the water in the river, and unless the galleries were placed below its lowest water they would obviously become dry and would cease to deliver at its lowest stage. These galleries are of various sizes and of various widths, 8 to 30 ft. in width being the latest practice. But the experience of one place will seldom be applicable to another. The character of the neighbouring stream and the fineness or coarseness of the gravel or sand in which the galleries are placed, influence importantly the rate of supply.

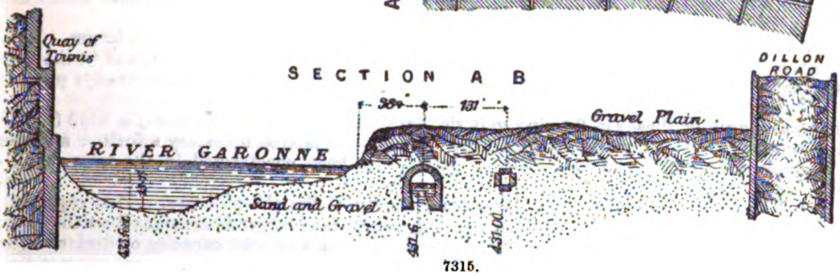
Figs. 7314 to 7317 are of the filtering galleries at the Toulouse water-works. The population of Toulouse is stated to amount to 100,000 souls. The water is derived from the Garonne, indirectly, by means of subterranean galleries situated in a bank of gravel on the left bank of the river. The sources of the Garonne are found on the slopes of the Pyrenees chain of mountains, in the department of Ariege. The velocity of the river at Toulouse averages ordinarily 1 mètre a second, or about 2¼ miles an hour. Immediately opposite the filtering ground the velocity does not exceed 2 miles an hour, the dam erected a short distance below having modified importantly the current there. The bank of gravel and sand in which the galleries have been constructed lies within the city limits, but in what may be called the suburbs; the dense portion of the city lies below this point as regards the river, and upon its opposite bank.

It is important to understand the relation of this gravel bank to the lowest stage of the Garonne, and to its flood waters. The surface water of the Garonne at its lowest stage is recorded to have stood 433 ft., $132^{m}\cdot09$, above the level of the sea. The surface of the gravel bank referred to is on an average 136 mètres, 446 ft., above the same level, or about 13 ft. above the lowest stage of the river. The river floods rarely cover this bank; in long intervals, however, extreme floods set over it, and the one of 1832 rose to 451½ ft., 137·69, above the sea, covering this gravel meadow, therefore, with some 5½ ft. of water. The rise of the river in ordinary floods may be taken at 8 to 10 ft. In the highest flood on record referred to it rose to 18 ft. above the lowest water of the river opposite to the present pumping engines.

In the pump-house there are two breast-wheels, each 16½ ft. diameter, exclusive of the buckets, and 5 ft. wide each. Each wheel works four plunger-pumps of 10½ in. (0·27) diameter each, and

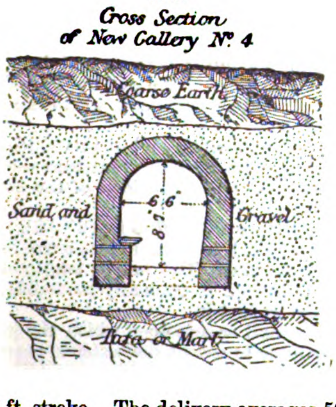
7314.





7315.

7316.



7317.

3·80 ft. stroke. The delivery averages 5000 cubic mètres a day. Each set of four pumps delivers its water into a vertical pipe of 10 in. diameter, which is carried up the pump-house tower to a height of 66 ft. above ordinary water of the river. At this height, the waters of the two rising mains are delivered into two city mains of the same diameter, and the head thus acquired enables numerous fountains to be well supplied, and admits of the lower stories or ground floors of many of the houses receiving the water into the house. In this last respect, Toulouse is at present very imperfectly accommodated. There is no reservoir connected with the pumps, which are therefore

necessarily kept perpetually at work, except as one wheel must be occasionally intermitted for repairs.

The new works include a sufficient reservoir to defend the city against accidents to the works, and to admit of their more leisurely repair and examination. They are so arranged as to admit of the water being received into the highest stories of all the buildings.

The form and size of the gravel bed in which the filtering galleries are situated will be best understood by reference to Figs. 7314 to 7317. The deposit consists of gravel and sand of different degrees of fineness, its surface, however, covered with a thick bed of rich soil. The whole rests upon a compact tufa or marl, and the depth at which any filtering galleries can be laid is limited by this impervious base. The surface of the marl is situated here about 12 ft. below the low water of the river.

As much of the body of sand and gravel lies below the level of the water in the river, it is saturated with water, and this water, although evidently derived from the river and its affluents, has passed through such a width or depth of material at a very slow velocity, on the wide plains above, that it has been deprived entirely of the matter which gives the muddy hue to the stream. In the filtering galleries, therefore, it is found colourless and limpid. Immediately under the bed of the stream, or in too close proximity to it, this result would not probably have place. The first filter gallery or drain C D, Fig. 7314, was laid at a distance of about 60 mètres, 197 ft., from the bank. The bottom is situated only about 4 ft. below the lowest water of the river. The form is square, the interior width 1 ft. 8 in., the height 3 ft. The side walls were of brick laid dry, with a flagging stone for the cover, and with no paving on the bottom. The bricks were laid dry and the bottom left uncovered, that the water might have free access to the culvert. The inside of this culvert was filled up with small stones, probably to prevent the side walls, which were not in mortar, from being pressed inwards. The trench in which the culvert was laid was filled up again with the materials taken from it. A coarse gravel was found at the bottom of the trench mixed with flints. The gravel became finer as the depth lessened from the surface, and ended in a fine river-sand, covered at present with from 2 to 3 ft. of soil.

The length of this first filtering culvert is 656 ft.; it is said to have delivered at all times clear water; but the quantity was soon found to be insufficient for the demands of the city. To increase the supply, a second filtering arrangement was projected and built, differing somewhat in character from the first. In this second case eleven wells *g*, *h*, Fig. 7314, were sunk along the margin of the river, covering a distance of 300 ft. They were carried to the same depth as the culvert, and steined up with dry brick. The wells were connected together by iron pipes, and from their lower terminus a connection was made with the pump well of the pump-house. The water from this second filter turned out bad, and it has consequently been for some time in disuse.

A third filtering culvert *c*, *e*, *f*, was constructed on the same plan as the first, but larger. In the lower part of its course it is situated farther from the river than the first culvert, and in the upper part nearer to the river; the length is 1476 ft. (450 mètres). Like the first, it has always produced good and clear water.

The total length of these old filtering galleries (excluding the wells in disuse) is 2132 ft. The growing wants of the city and the increase of its population rendered necessary a further and more liberal supply of water, and a new filtering gallery has been constructed in the same bank of gravel.

It will be convenient to note here the water capacity of the old galleries. This capacity is equal to 5000 cubic mètres a day. The new filtering gallery is of larger dimensions than the others, and it is laid lower in the bed of gravel, and consequently has a greater capacity of drainage from the underground reservoir of the neighbouring plain, of which the particular gravel bank of these works may be said to form a part.

It differs in other respects importantly from the old filtering conduits. Its contour is of mortared masonry, in this case beton, of sufficient strength to defend it from the outer thrust of the material in which it is imbedded, and its interior is not filled with stones, but void, forming thus in itself a considerable reservoir of water. The water finds its way into the conduit from the gravel deposit in which it lies, in part by small earthenware tubes placed on both sides of the gallery, but mainly through the bottom, six-sevenths of which is left unpaved for that purpose, and where the clear water rises, therefore, from the coarse gravel which has place there.

At every seventh mètre a buttress is thrown across of 1 mètre in width, and to this extent the bottom is impermeable. The surfaces of these buttresses, which are intended to defend the side walls against movement from the back thrust, do not rise above the prescribed level of the bottom of the conduit.

The interior height of the new conduit is 8 ft. 8 in. ($2^m \cdot 65$), the width 7 ft. 6 in. ($2^m \cdot 30$). The bottom is placed at $129^m \cdot 45$ (424·6 ft.) above the sea, or 8 ft. 7 in. below the lowest stage of the river. It is therefore 4½ ft. below the bottom level of the old galleries. The present length of the new gallery is 1180 ft. (360 mètres); but the intention is to extend it gradually to double this length, or more, according as the requirements of the city may demand it.

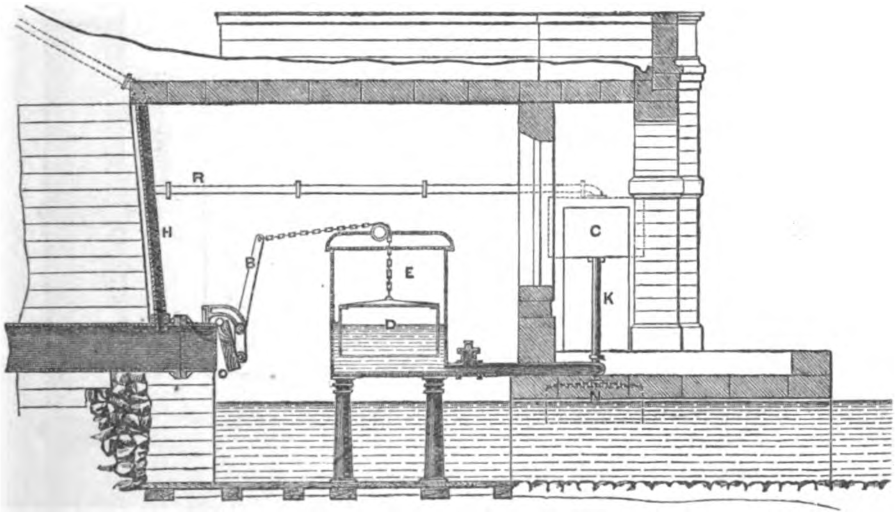
It will be observed that the new gallery is not based on the marl or tufa upon which the gravel bed rests, but is kept from 2 to 3 ft. above it. This has been done to permit the water to percolate easily into the gallery from the bottom, where it is expected that the mass of the water will enter it, rather than from the side tubes.

The dam in the river below the present pump-house produces comparatively still water opposite to the filter ground, and must encourage that kind of sedimentary deposit there, which the natural current of these rapid mountain streams does not admit of, except in eddies, and then only until the scouring operation of a heavy flood clears the channel of such accumulations. But when the underground material of the plain, for some distance above, consists of an equally open gravel, it can be of little consequence that the river bottom, within the influence of the dam, should become comparatively water-tight. The water will, in any case, reach the filter galleries from above, and

from a somewhat greater distance, and the only effect would be to reduce the rate of delivery somewhat, and perhaps render a greater length of gallery necessary.

Water Regulator.—To ensure a constant discharge of water from a reservoir which has a head of water varying continually, a water regulator is frequently used. Several methods have been adopted, one of the most ingenious is that used at the Gorbals Water-works, near Glasgow. Fig. 7318 represents a transverse section of this arrangement through the regulator-house, showing the method by

7318.



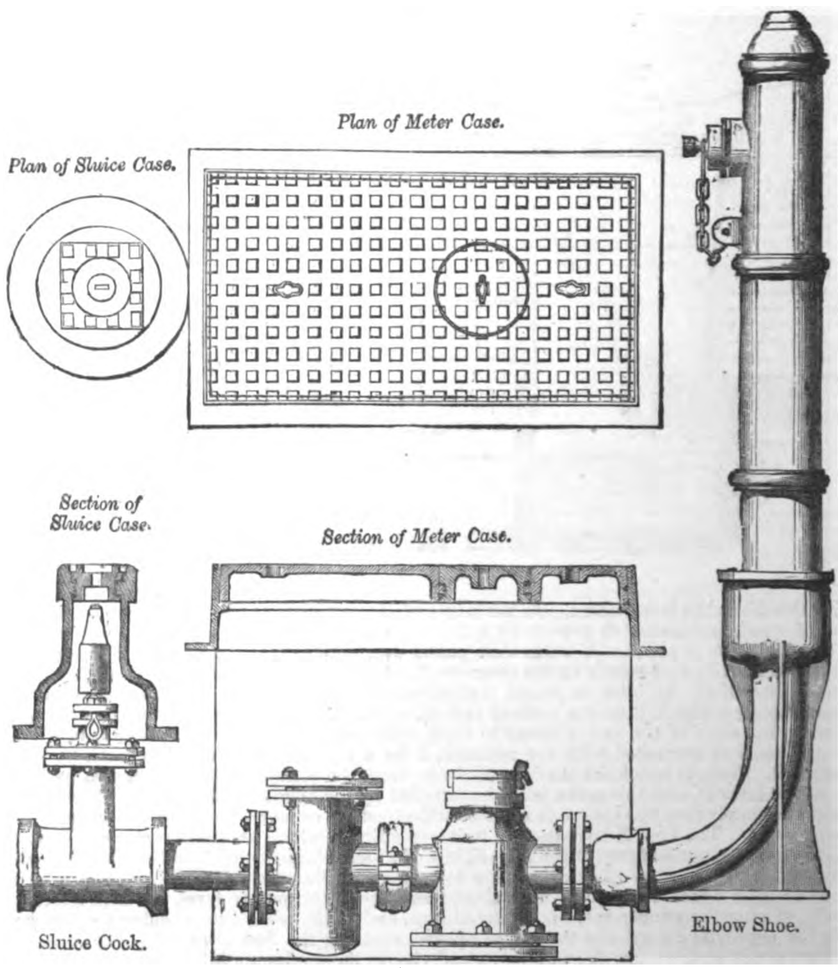
which the discharge is equalized. To the orifice of the outlet-pipe O is fitted a square-hinged flap-valve of wood, against which presses, by a friction roller, a lever B, the arms of which are bent. To the upper arm is attached a chain that passes over a pulley, and is connected with a cast-iron cylinder or float D, that stands in the reservoir E, of slightly larger diameter. At the side of the entrance door of the building is placed another cistern G of cast iron, closed at the top and communicating by a pipe R R with a vertical pipe H, which is in connection with the outlet-pipe, and passes up the slope of the embankment to carry away any air that may accumulate in the main. The cistern G is connected with the reservoir E by a pipe K, which supplies water to float the cylinder D. Now, it is evident that the discharge from the reservoir will be regulated by the position of the lever B, and this again will be controlled by the height of the float D. To regulate this height the supply from the cistern G must be self-adjusting, or be regulated by the amount of water flowing away. The float N has attached to it a spindle, on which are fixed two double-beat valves that work in the vertical part of the pipe K, one of which admits water from the cistern G into the cylinder E, and the other allows the water to escape from the reservoir E. Now, if the surface of the water upon which the float N rests should rise above the proper level, the float forces up the spindle, closing the supply-valve from the cistern, and at the same time opening the lower valve. Thus the supply is cut off and the escape opened, enabling the float D to fall. The subsidence of the float closes more or less the flap-valve, and checks the discharge, in consequence of which the surface of the water falls, and with it the float N, which consequently opens the supply-valve, and again admits water into the cistern E. Thus an almost perfect equality between the consumption and the supply-water is preserved. It would appear that the same effect could be produced by connecting the lever directly with a float on the surface of the water, but such an arrangement would only apply when the pressure against the flap is trifling.

General Remarks.—In arranging a main pipe from pumps, the pipes should have sectional capacity sufficient to allow of the velocity in the main pipe not exceeding 2 ft. a second, as friction increases in proportion to the velocity, as is shown by the law governing the delivery of water from pipes under pressure. Covered reservoirs and tanks should be ventilated, and all supply-pipes arranged in such manner as to allow of easy inspection and subsequent repairs. Stop-taps should be placed betwixt the main and the building in all cases, so as to allow of isolation of any line of service-pipe for repairs. House service-tanks and service-pipes ought to be fixed so that the rooms cannot be flooded in case of leakage or overflow, and ready means of access to all tanks and cisterns must be provided to allow of inspection, cleansing, or repairs. Up-bends should not be formed on lines of main pipes or on service-pipes. If up-bends are inevitable, air-valves have to be provided to let out the air at the up-bends. Bends at right angles on pipes are to be avoided, and the pipe brought round in a curve instead.

In most towns it is necessary during the summer months to distribute water over the streets in order to mitigate the inconvenience arising from clouds of dust, to cool the atmosphere, and to assist in flushing the drains. Hydrants, which can be also used to communicate with fire-hose or stand-posts, are therefore attached at certain intervals to the mains; and in estimating the quantity of water required in any particular town, the quantity required for fires and street-watering must

be taken into account. Figs. 7318A, 7318B, a plan and section of a street-watering apparatus, fitted with a water-meter. The water is admitted from the main through the sluice-cock, passes through the meter, and thence by the iron elbow into the stand-post, from which it is delivered into the water-carts.

7318A.



7318B.

Paisley Water-works.—The following account of the water supply of the town of Paisley, for which we are indebted to Alexander Leslie, will serve to illustrate many of the points we have already enlarged upon.

In the year 1835 powers were obtained to bring in water, for the supply of Paisley, from the districts of Gleniffer and Harelaw, Fig. 7319, lying to the south of the town, having respectively drainage areas of 624 acres and 166 acres. The works were executed by R. Thom, who made careful experiments, extending over a period of three years, to ascertain the amount of water flowing from the Gleniffer district, by means of which the quantity actually available was found to be 70,354,769 cub. ft. a year, which is equivalent to 31·06 in. out of a depth of 46·13 in. of rain over an area of 27,189,063 sup. ft., leaving a loss by evaporation and absorption of 15·07 in. The whole of the water from the drainage area was not available for the use of the town, as one-fourth was reserved for compensation to bleach-fields situated on the natural water-courses. This amounted to 22,267,735 cub. ft. a year, leaving 66,803,206 cub. ft. available, being 183,022 cub. ft. a day, or 127·1 cub. ft. a minute.

The works consist of a reservoir at Harelaw, having a capacity of 14,248,000 cub. ft., with a conduit leading from thence to Stanely, where there are two other reservoirs, one to act as a subsiding pond, capable of holding 28,340,000 cub. ft., the other for clear water, with a capacity of 7,194,000 cub. ft., with regulating sluices for turning the water into either. The open conduit between Harelaw and Stanely is the principal feeder for the Stanely reservoirs; in its course it intercepts the burns flowing from Gleniffer braes, which are almost all pasture ground.

There are self-acting compensation sluices at the outlet of the lower of these reservoirs to ensure a uniform delivery with a varying head of water in the reservoir. From thence the water is con-

7319.

veyed by a masonry conduit, 2 ft. by 1 ft. 6 in., to filters and a covered tank, on an elevation at the southern end of the town. The population in 1853 was about 50,000, so that the supply of water for each person, including manufactories, was 22½ gallons a day.

The growing wants of the town rendered it necessary for the authorities to look out for increased supplies, and, after examining various sources, the water of the Rowbank burn, which rises on the borders of Renfrewshire and Ayrshire, and which is one of the tributaries of Castle Semple Loch, was selected. The average height of the land selected for the reservoir is 500 ft. above the Ordnance datum, rising in undulating ridges to 700 ft. at the watershed. The works have also to supply the town of Johnstone and the village of Elderslie, having together a population of nearly 10,000 persons.

The drainage area utilized by the engineer to the new works, James Leslie, contains 1220 acres, and is partly arable, partly pasture, and $\frac{1}{13}$ of the whole, amounting to 94 acres, is moorland, the water from which is rather mossy at times, but this is diverted from the store reservoir, making it however available for compensation. Two rain-gauges were placed in the neighbourhood, of which a careful register was kept. One of these, representing the rainfall over 700 acres, was at Springside, 540 ft. above the sea, and the other, the fall over 520 acres, at Muirhead, at a height of 490 ft. above the sea. It was thus ascertained that the yearly fall at Springside equalled 64·39 in., and at Muirhead 50·79 in.

The quantity of rain falling on 700 acres, the depth being 64·39 in., is equal to 163,614,990 cub. ft., and on 350 acres, the depth of rain being 50·79 in., 64,528,695 cub. ft. The average depth of rain over the whole area is 59·86 in., or 228,143,685 cub. ft., and subtracting the amount measured by the weirs, subsequently mentioned, 179,662,325 cub. ft., there remain for loss by evaporation and other causes 48,481,360 cub. ft., which is equal to 12·72 in. of the rainfall, leaving 51·67 in. available for the high ground and 38·07 in. for the low ground. There now remain 170 acres, with a rainfall of 38·07 in. to be added, which yield 23,492,997 cub. ft. of water a year, raising the total to 203,155,322 cub. ft. a year. A stone reservoir was constructed at Nethertrees, on the Rowbank or Birkcraig burn, about three miles south-east of Lochwinnoch; the water area is 100 acres, and the greatest depth 35 ft. The pipes were constructed to carry 184 cub. ft. of water a minute, and the compensation water was fixed at 92 cub. ft. a minute. Storage was provided for 180 days, or six months of this whole quantity, being about 77,000,000 cub. ft.

To test the flow of water into the Rowbank reservoir four gauge-weirs were erected on the tributaries, and the water flowing over them was measured every day. These gauges were constructed of battens and stakes carefully levelled and made water-tight, with a free overfall, and with sufficient still water behind to prevent inaccuracy from initial velocity. No. 1 was 5 ft. long; No. 2, 2 ft. 4 in.; No. 3, 1 ft. 4 in.; and No. 4, 1 ft. The depths being taken, were calculated by the formula $Q = 4\cdot904\, b\, d^{\frac{3}{2}}$, where Q = cubic feet a minute, b = breadth in feet, d = depth in inches. The total flow a year over all the weirs was:—For No. 1, 129,484,049 cub. ft.; No. 2, 38,359,063; No. 3, 7,262,279; No. 4, 4,556,934; total, 179,662,325.

A conduit, 6¼ miles long, conducts the water to the Stanely filters, whence it is conveyed to Paisley by a 16-in. pipe. A branch pipe leaves the main 3 miles west of Paisley to supply the towns of Johnstone and Elderslie; and a set of filters and a tank were constructed at Craigenfeoch for filtering the water supplied to those places. Another set of filters and a tank are placed on the high ground to the south of the original reservoirs at Stanely, with a branch pipe leading down to them, to make up any deficiency that may occur in the old works.

To impound the water it was found necessary to construct three embankments, the largest of which is situated across the bed of the burn or stream at Nethertrees. The first operation consisted in the formation of a by-wash channel, to divert the water of the Reivoch burn from the reservoir during the construction of the bank, as it was from this burn that floods were apprehended; and it now serves for carrying the water of that burn past the reservoir, should it be at all impure owing to floods. When this was finished the outlet-tunnel, Figs. 7320 to 7322, was proceeded with. The purpose of this was, in the first place, to discharge the waters which would have accumulated during the construction of the bank, and to receive the two outlet-pipes, one of which carries the compensation water, and the other the water for the town. The tunnel is 426 ft. long, a length of 150 ft. of which, at the lower end, was open at first, and afterwards covered in, the remaining 276 ft. being tunnelled through rock. The interior dimensions of the tunnel are 5 ft. 6 in. by 5 ft. 6 in. It has vertical side walls, and a semicircular roof. The whole length of the arch was built of moulded brick. Where in open cutting the side walls were 15 in. thick, and the arch was built of the same

7320.

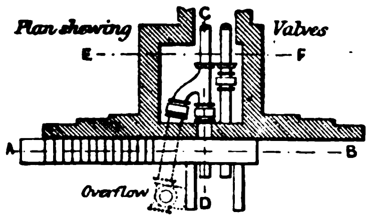
7321.

7322.

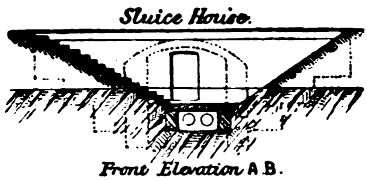
thickness, set in mortar, with a rubble-stone arch outside, 9 in. deep; and where in tunnel the side walls, for a length of 236 ft., were built of brick, and the space between the wall and the rock was filled in with close-packed rubble stone set in mortar. A length of 40 ft. at the inner end, where the rock was friable whin, a kind of trap or green-stone, was built wholly of brick set in cement, the brickwork filling up the entire space to the rock. This portion had a brick invert varying from 9 in. to 15 in. in thickness set in cement, the remainder of the floor of the tunnel being natural rock, dressed off as smoothly as possible. The rock varied in quality from what is locally called Osmond, being like the hardest whinstone, to a soft grey, granulated, sedimentary substance, easily cut with a knife. It required blasting, and in some places the roof had to be supported until the building was finished. At the lower end of the tunnel is the sluice-house, Figs. 7323 to 7326, 10 ft. square, with an arched roof 10 in. thick, and side walls 3 ft. thick, in which are placed three sluices for

directing the water into the town, or for diverting it into the burn. At the inner end of the tunnel is a horseshoe-shaped recess of masonry, Figs. 7327 to 7330, in which is placed the iron up-stand or

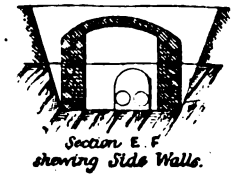
7323.



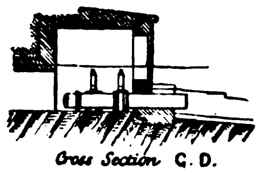
7324.



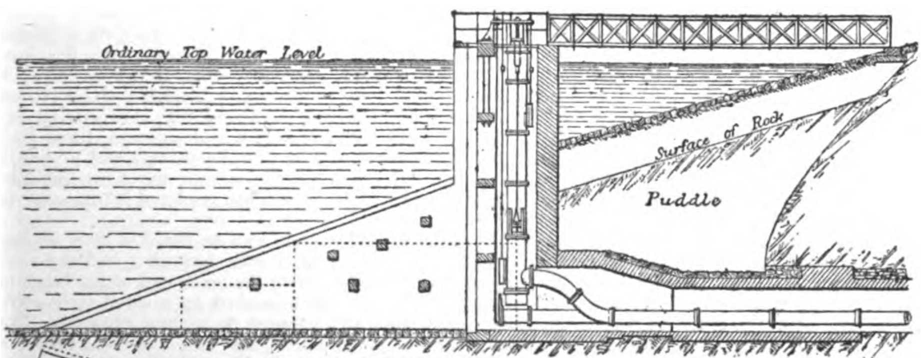
7325.

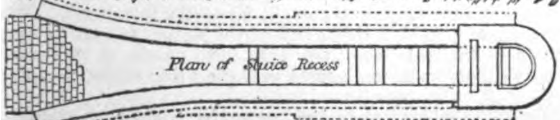


7326.



7327.

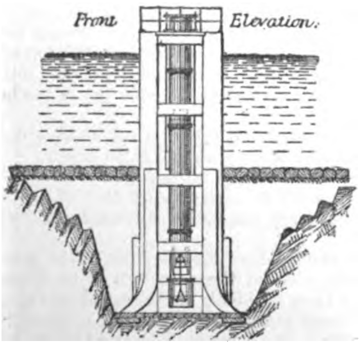




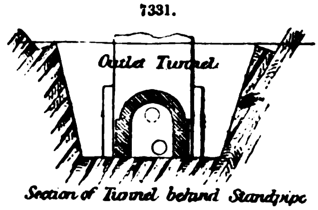
7329.

7330.

7328.



7331.

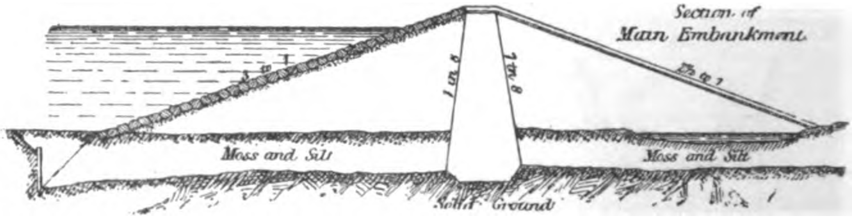


sluice-shaft. This recess is 10 ft. 9 in. long by 5 ft. 9 in. broad, with walls 2 ft. 6 in. thick. Across the front are lintels 2 ft. 6 in. by 1 ft. 3 in. in section, and, again, in front of these is a groove for holding a wooden grating, which may be replaced by stop planks when access to the sluices is

required. Across the bottom, and 2 ft. 6 in. above the floor, is a stone 3 ft. by 1 ft. 9 in. in section, on which stands the iron sluice-shaft, and below which passes the pipe conveying the compensation water. For a length of 17 ft. at the upper end, the tunnel is of larger dimensions, being 7 ft. 6 in. by 5 ft. 6 in., and tapering to 5 ft. 6 in. by 5 ft. 6 in., Fig. 7331. This portion was filled up with masonry round the pipes, after the embankment was completed, to make it water-tight; and round the up-stand, up to the level of the ground, it was filled in with clay puddle and covered with pitching. Leading to this up-stand is a channel 5 ft. 9 in. wide, Figs. 7327, 7328, with side walls varying from 2 ft. 6 in. to 3 ft. 6 in. thick, with cross lintels 1 ft. square to keep the walls apart, and the bottom is pitched with 9-in. pitching set on a bed of concrete 6 in. thick. The ashlar was procured from Shillford quarries, 4 miles south-east from the reservoir. Provision was made in the contract for filling up the tunnel with clay round the outside of the pipes, but this has not been required, as the solid masonry at the upper end is water-tight.

The greatest depth of the principal bank is 60 ft., Fig. 7332, and the length 500 ft. along the

7332.



top, which is 5 ft. above high-water level, and 10 ft. broad. The slopes are 3 to 1 inside and 2½ to 1 outside. The puddle is 8 ft. broad at the top, and increases with a batter of 1 in 8 on each side down to the level of the ground, from which point it diminishes to one-half that width at the bottom of the trench. The puddle-trench is 62 ft. deep at the deepest part. To form a proper foundation, all soft material was stripped off the site of the bank, including a considerable accumulation of peat and silt at the bottom of the valley, which was excavated down to the clay or rock before the bank was commenced. The greatest depth under the surface of the valley was 17 ft. on the outer, and 22 ft. on the inner side. During the excavation it was found that the moss on the inner side was so soft that it would not stand even with a moderately flat slope; and it was also threatening to cause a leak in the temporary bank across the valley. To obviate this, and to enable the moss and silt to be readily cleared out, a row of piles was driven at the inner toe of the embankment. The broken nature of the rock forming part of the puddle-trench rendered it necessary to excavate the hills on both sides to a considerable depth.

The material for the bank was found on the site of the reservoir, and consisted of clay, which, when mixed with the rock taken from the excavation of the puddle-trench, formed a good and substantial bank. To facilitate the work a short tramway was laid from the north end of the bank to the place where the materials were procured. The wagons were worked by a small locomotive engine, and the stuff, having been tipped on a loading bank, was removed in common tip carts. The banks were then formed with a slope inwards towards the trench of 1 in 12. Care was taken to spread all stones and keep them separate, so that earthy matter might fill up the interstices. The layers, each 6 in. thick, were pressed and trodden down by carts and horses passing frequently over them, and were pounded with beaters where the carts could not work. No planks or rails were allowed in forming the banks, and in dry weather water was poured over the whole surface to make it settle.

The wagons for conveying the puddle were also worked by the locomotive engine. A staging, carrying rails, having been formed along the side of the trench, the wagons ran along it by their own gravity, and the clay puddle was tipped into the trench; it was then spread in thin layers, mixed with water, and properly cut and worked up by being tramped on by navvies. After undergoing this process, it formed a compact mass quite impervious to water. When the slopes of the bank had been made, and had settled, the inside slope was covered with a layer of broken stones, over which was laid pitching of hard blue whinstone. On the outer slope, and on the top of the bank, was laid a layer of stones 3 in. deep to keep out moles and rats, over which a layer of soil was dressed off, and sown with rye-grass and clover seeds. The natural slopes between two of the banks were pitched with rough pitching, set on a layer of broken stones.

The other banks were formed in the manner already described, but they were of smaller dimensions, one being 230 ft. long and 14 ft. deep, and the other 815 ft. long and 18 ft. in depth.

The waste weir at the south end of the large bank was 40 ft. long, being at the rate of 1 ft. in length for every 30 acres of drainage area. The side walls are 3 ft. high on each side of the weir, and the channel, which has a gradient of about 1 in 6, has been cut out of the solid rock, with a width at the bottom of 10 ft.

It was originally intended to strip the entire surface of the inside of the reservoir, as the presence of vegetable matter was considered objectionable; but the cost led the operation to be dispensed with. The quality of the impounded water, however, has been decidedly deteriorated by the omission of this operation. When the bank and waste weir were finished, two parallel lines of 21-in. pipes were laid through the tunnel; at the inner end one was connected to the bottom of the cast-iron up-stand shaft, and the other passed under the stone carrying the sluice-shaft, and was bolted to the sluice for giving out compensation water. The space under the stone was then built up. These pipes, which were in 12-ft. lengths, were lowered by a crane on a bogie at the sluice-house end of the tunnel; a tramway having been laid through it, the pipe was then run up to

the place required, and when on the bogie, it was used as a ram to drive the preceding pipe tight home.

The sluice up-stand, in the horseshoe recess, Fig. 7327, is made of cast iron. It is 2 ft. 6 in. in interior diameter, of $\frac{3}{4}$-in. metal, cast in five pieces, with flanges bolted together. It is about 35 ft. high, and there are four sluices at different levels. The sluice openings are 17 in. square, and are fitted with double brass faces. The pipe for the town supply is connected with this cylinder, and at a lower level is the pipe for the compensation water, with the rod for working the sluice on the end of it, passing up in front of the iron cylinder. The sluices are worked by a movable brass nut working on a $2\frac{1}{2}$-in. screw. The compensation water is discharged into the burn or stream, across which is placed a gauge-weir to measure the amount of water. The water for the town is discharged into a cast-iron well, with an overflow to take the pressure off the clay pipe which leads from it towards Paisley.

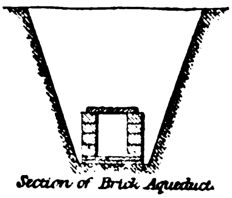
The total length of pipe track from Rowbank reservoir to Stanely is 11,126 yds. For a distance of 3872 yds. this track has a gradient of 1 in 700, and is laid with 3021 yds. of 21-in. clay pipes, 76 yds. of iron pipes in moss, with a few iron pipes at the burn crossings, and there are 765 yds. of masonry aqueduct where the track is in deep cutting. The second portion of the track is supplied with cast-iron pipes, of which 3286 yds. are 18 in. in diameter, and 367 yds. 16 in. The third portion has 16-in. clay pipes for 2700 yds., laid at a gradient varying from 1 in 140 to 1 in 70, and 200 yds. of iron pipes. The portion from Stanely to Paisley, 2895 yds. in length, has 16-in. iron pipes. The pipe for supplying Johnstone and Elderslie leaves the 18-in. main near Craigenfeoch, and is 8 in. in diameter to the filters, from thence it is 10 in. to Thorne, from which place there is a branch to Johnstone 8 in. in diameter, and another to Elderslie 5 in. in diameter. The track for the pipes was excavated 1 ft. wider at the bottom than the exterior diameter of the pipe, with slopes varying according to the quality of the material; opposite each faucet a clear space of 6 in. was left all round, to permit of the proper jointing of the pipes. When the cutting was in rock, the pipes were laid on a bed of earth 3 in. deep. Where the clay-pipe track was through a porous material, the pipes were surrounded with clay puddle 12 in. thick. The clay pipes were jointed in the following manner;—Two strands of rope-yarn, steeped in thin cement, were wrapped round the spigot and calked in after being inserted into the faucet; then the remainder of the faucet was carefully and closely filled up with cement, which was bevelled out from the end of the faucet along the outside of the pipe, with a slope of 1 to 1, and when practicable, as in the case of the 21-in. and 16-in. pipes, a boy was sent in to point the inside of the joint with cement.

Wherever there is a constant fall and no pressure on the pipes, says Leslie, clay pipes should be found to answer the purpose well, provided sufficient care is taken in selecting those perfect in form and without cracks or flaws, especially at the neck where the faucet is fastened on to the body of the pipe, and where a crack is likely to be found. Care must be taken, too, that they are properly jointed, and that the thin cement is not shaken out of its place during the operation of refilling the track, a probable result if it is done before the cement has had time to set. Above all, they should not be laid in too deep cutting, as the superimposed material is certain to break and crush them; nor should they be subjected to any pressure from a head of water.

The great fault found in the pipes was a liability to crack at the junction of the faucet with the body of the pipe. A method was devised in order to test their soundness, when that could not be ascertained by ordinary inspection. The pipes were placed on a wooden platform, with the faucets downwards, and inserted in a thin bed of clay carefully worked so as to be water-tight. The pipes were then filled with water obtained from a pit close by. With a head of 3 ft. of water some of them were found to leak, though the greater number were perfectly tight. The cracks in those which leaked were carefully pointed with Portland cement inside and outside. When the cement had set, they were again subjected to the water test, and for the most part they were now found to be water-tight; those that still leaked were rejected.

Where clay pipes were used in cuttings above 9 ft. deep, a relieving arch of rough rubble was formed over them to protect them from crushing. Where the depth of cutting exceeded 12 ft., a masonry aqueduct was substituted for the clay pipe, the sectional area of which was 3 ft. by 2 ft., Figs. 7333 to 7335. The soles were of pavement about 3 in. thick, which was set flush in mortar

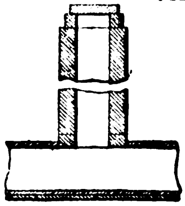
7333.



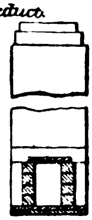
Section of Brick Aqueduct.

7334. 7335.

Manhole on Aqueduct.



Section.



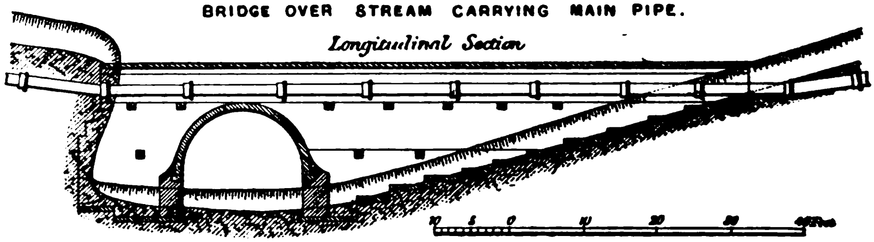
Elevation.

on a bed of levellings and well pointed. The sides consisted of parapet ashlar, procured from Shillford quarries, 9 in. broad, with the faces scabbled and the backs left quarry-faced; and the covers were of pavement from 3 in. to 5 in. thick, with a rest of 6 in. on each wall. Where part of the conduit was in treacherous ground, the soles and covers were checked, so as to keep the walls apart should there be any tendency to force them together. Great care was taken in filling the space behind the ashlar with clay and soft material, and a depth of 1 ft. 6 in. to 2 ft. of earth was placed on the top of the covers to protect them in filling in the cut, which in most cases was in rock. Where the track

passes under streams an iron pipe is substituted for the clay pipe. This is built round with rubble, over which is placed hammer-dressed pitching 10 in. or 12 in. deep, and in the centre, over the pipe, pavement is laid of a thickness and extent depending on the size of the stream. One stream is crossed by a bridge of 16 ft. span, Figs. 7336 to 7338. The arch stones are 15 in. deep, and the side walls are tied together with bond stones with a hold of 12 in. at each end.

7336.

BRIDGE OVER STREAM CARRYING MAIN PIPE.



The clay pipes were of the following dimensions, all being 3 ft. long, exclusive of the faucet;—

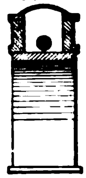
Internal diameter.	Thickness.	Depth of faucet.
12 in.	1 in.	4 in.
15 "	1 "	4 "
16 "	$1\frac{1}{4}$ "	$4\frac{1}{4}$ "
21 "	$1\frac{1}{2}$ "	$4\frac{1}{2}$ "

The faucets are of $1\frac{1}{2}$ in. greater diameter than the outside of the pipes, and are $\frac{1}{8}$ in. thicker than their body; the shoulder is $\frac{1}{4}$ in. thicker than the body of the pipes, and both spigot and faucet are grooved to make them hold the cement.

The iron pipes were 12 ft. long exclusive of the faucet. The principal dimensions and weights of these pipes were as follow;—

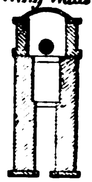
7337.

Section through Arch



7338.

Section through Wing Walls



Interior Diameter.	Length of Pipe exclusive of Faucet.	Length of Pipe, inclusive of Faucet.	Thickness of Body of Pipe.	Weight of each Length.
inches.	feet.	feet. inches.	inch.	cwts. qrs. lbs.
5	12	12 4	$\frac{1}{2}$	3 0 15
8	12	12 $4\frac{1}{2}$	$\frac{9}{16}$	5 1 26
8	12	12 $4\frac{1}{2}$	$\frac{5}{8}$	6 0 15
10	12	12 $4\frac{1}{2}$	$\frac{5}{8}$	7 2 6
10	12	12 $4\frac{1}{2}$	$\frac{11}{16}$	8 1 13
16	12	12 $4\frac{3}{4}$	$\frac{3}{4}$	14 1 5
17	12	12 $4\frac{3}{4}$	$\frac{3}{4}$	15 0 16
18	12	12 $4\frac{3}{4}$	$\frac{3}{4}$	16 0 0
18	12	12 $4\frac{3}{4}$	$\frac{13}{16}$	17 1 15
21	12	12 5	$\frac{13}{16}$	20 0 22
22	12	12 5	1	26 0 18

The pipe-joints were, for the most part, turned and bored, and the pipes were laid in the following manner;—The spigots were wiped clean, and were coated with fresh Portland cement of the consistency of paint made up immediately before being used. They were then inserted into the faucets and the pipe driven home by repeated blows, in the case of the smaller pipes from the wooden mallet, and in that of the larger pipes with the next one slung as a ram, in which case a piece of wood was interposed to keep the iron from striking iron. The lead and yarn joints were made after the spigot was inserted, by calking the faucet hard with sound rope-yarn up to within $2\frac{1}{2}$ in. of the outside, and filling the remaining space with melted lead, which was hard staved so as to be watertight.

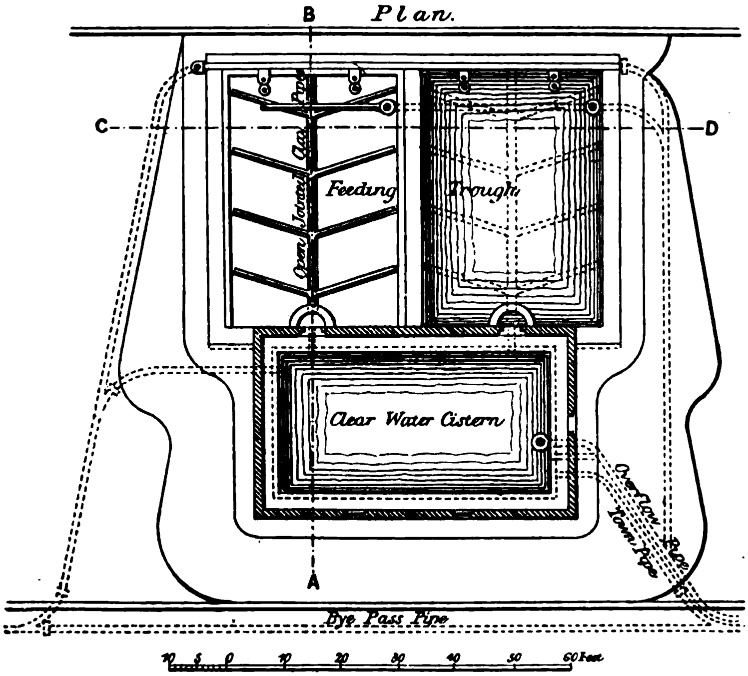
The pipes were tested with the pressure of a column of water, which for a pipe

in.		in.		ft.		in.		in.		ft.	
5	in diameter and	$\frac{1}{2}$	thick, was	600	high.	17	in diameter and	$\frac{3}{4}$	thick, was	300	high.
8	"	$\frac{9}{16}$	"	300	"	18	"	$\frac{3}{4}$	"	300	"
8	"	$\frac{5}{8}$	"	600	"	18	"	$\frac{13}{16}$	"	400	"
10	"	$\frac{5}{8}$	"	300	"	21	"	$\frac{13}{16}$	"	300	"
10	"	$\frac{11}{16}$	"	600	"	22	"	1	"	400	"
16	"	$\frac{3}{4}$	"	300	"						

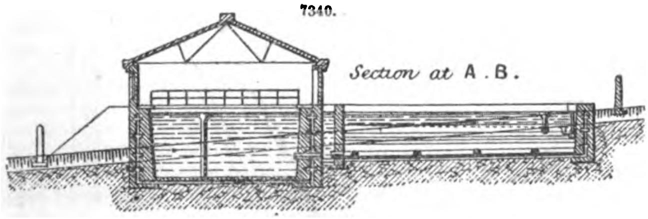
While under pressure they were repeatedly struck with a hand hammer, and any pipes sweating or leaking were rejected. The uniformity of their thickness was also tested by calipers designed for the purpose.

Two filters, Figs. 7339 to 7341, for the supply of Johnstone and Elderslie, were constructed at Craigenfeoch, each 45 ft. by 32 ft., and the tank was 50 ft. by 26 ft. and 13 ft. deep.

7339.

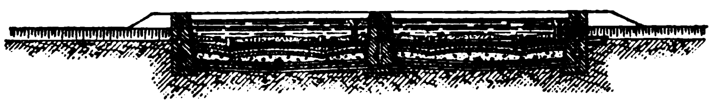


7340.



7341.

FILTER



Section at C . D.

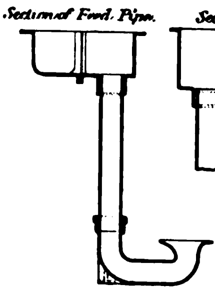
Fig. 7342 is a section of the feed-pipe; Fig. 7343 a section of the feed-trough; Fig. 7344, section of the inlet-pipe and trough; Fig. 7345, overflow-pipe for filter; Fig. 7346, regulating sluice; and Fig. 7347, by-pass sluice for filter; Figs. 7348 to 7351, outlet-sluice for town-pipe, with screen.

The walls of the filters and tank have a foundation course 8 in. thick, and are built of good flat rubble bedded in mortar, and the face stones of the tank and of the filters above the level of the sand are of chisel-draughted ashlar. The tank walls are 3 ft. 6 in. thick, at the level of the platform, and the filter walls are 3 ft. thick; both have a batter on the inside of 1 in 12.

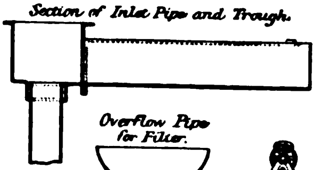
As the excavation consisted for the most part of porous rock, the whole area of the building was well grouted with mortar run into every crevice, and the floor of both filters and tank, including half-way through the walls over the foundation course, was covered with a layer of clean gravel, 4 in. thick, grouted flush with Portland cement. The retaining walls were brought up with a void of 4 in. in the heart, with two dovetailed recesses to form a tie opposite each other 12 in. by 6 in. by 6 in. for every square yard of surface. These voids were filled with clean gravel in layers of 6 in. connected with the concrete of the floor, and each layer was grouted with Portland cement. The result was an excellent water-tight wall, the only objection being the cost, which was high. The floor of the tank was covered with pavement 3 in. thick, laid flush in mortar and pointed with cement, and an area of 6 sq. yds. under the inlet-pipe was laid with ashlar 9 in. deep, calked on

the joints with iron-rust cement. There are two semicircular wells at the outlet of the filters, with sluices for regulating the head of water over the filters during filtration. The filters have each a

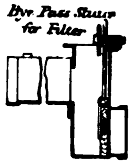
7342.

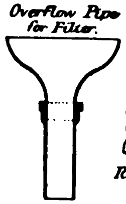


7344.

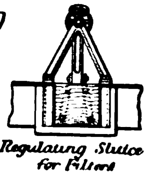


7347.

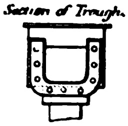




7345.



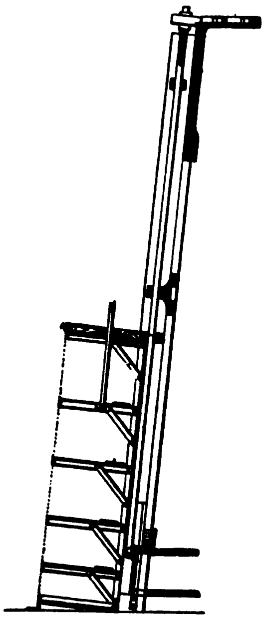
7346.



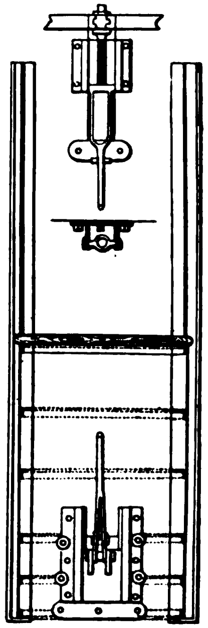
7343.

12-in. clay pipe along the centre, with branches and 4-in. cross-pipes laid with open joints to admit the water, and with an iron air-pipe at the end of each. The filtering material consists of a bed 2 ft. deep of coarse gravel, small enough to go through a 2-in. ring, but not through a ¾-in. ring; the upper surface is in ridges and furrows 6 in. deep, and over that is a layer 6 in. deep of clean gravel which will go through a ¾-in. screen, but not through a ⅜-in. screen; over this is a layer of slate chippings 6 in. deep, then a layer of coarse sand 6 in. deep, and lastly a bed 18 in. thick of fine clean sharp sand, dressed into the prescribed form of ridges and furrows, Fig. 7341. The water is admitted into the filters by feeding troughs along the side farthest from the tank, from which it passes through sluices and feeding chests into the feed-pipe, and is delivered from a trumpet mouth at the level of the sand, which prevents any disturbance of the filtering material.

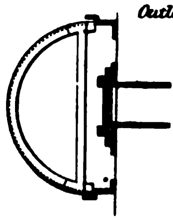
7348.



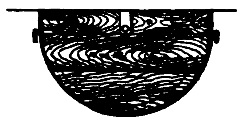
7349.



Outlet Sluice for Town Pipe with Screen.



7350.



7351.

The roof of the tank is of wrought iron with T bar rafters and struts, and round tie and suspension rods, 6 ft. apart, braced diagonally, resting on and bolted to a cast-iron wall-plate, and having L lathes 8½ in. apart for the slates. The slates, which are Welsh seconds, 20 in. by 10 in., are fastened on by copper wire to the lathes, overlapping 3 in. The mortar employed was Arden lime well burned and ground, mixed in the proportion of two and a half parts of lime to two of sand and one of mine dust. The high-level filters and tank erected at Stanely are of the following dimensions; three filter beds each 90 ft. by 60 ft., and a tank 138 ft. by 38 ft. and 14 ft. deep. They are constructed on the same principle as those above described, the only difference being that the walls of the tank are 4 ft. 6 in. thick at the top; all the walls inside batter 1 in 10, but for economy the concrete groove was dispensed with, and on the outside of the walls clay puddle was substituted for it.

Works relating to Water Supply;—'Report by the General Board of Health on the Supply of Water to the Metropolis,' 8vo, 1850. Kirkwood (J. P.), 'Reports on the Use of Lead Pipe for Service Pipe in the Distribution of Water for Cities,' 8vo, New York, 1859. 'Distribution de l'Eau potable dans les Fontaines et dans les Maisons particulières de Berlin,' imperial folio, Berlin, 1860. Dumont (A.), 'Les Eaux de Lyon et de Paris,' 2 vols. 4to, sewed, Paris, 1862. Morin (A.), 'Des Machines et appareils destinées à l'élévation des Eaux,' 8vo, Paris, 1863. Gale (J. M.), 'On the Glasgow

Water-works,' 8vo, Glasgow, 1864. Dupuit (J.), 'Traité théorique et pratique de la conduite et de la distribution des Eaux,' 2 vols. 4to, Paris, 1865. 'The Brooklyn Water-works and Sewers, a descriptive Memoir,' 4to, New York, 1867. Colburn and Mawe, 'The Water-works of London, 8vo, 1868. Kirkwood (J. P.), 'Report on the Filtration of River-water in Europe,' 4to, New York, 1869. Chapman and Wanklyn, 'Water Analysis, a Practical Treatise on the Examination of Potable Water,' crown 8vo, 1870. Hughes (S.), 'On Water-works for the Supply of Cities and Towns,' 12mo, 1872. See also numerous papers in the 'Minutes of the Institute of Civil Engineers.'

WEB. Fr., *Core;* Ger., *Gewebe;* Ital., *Costola;* Span., *Nervio.*

A web is a thin vertical plate of metal connecting an upper and lower part or table of a girder.

WEDGE. Fr., *Coin;* Ger., *Keil;* Ital., *Zeppa, Cuneo;* Span., *Cuña.*

A wedge is a piece of metal or other hard material, thick at one end and sloping at the other to a thin edge, used in splitting wood, rocks, and the like; in raising heavy bodies, and for similar purposes. See Mechanical Powers.

WEIGHING MACHINE. Fr., *Balance;* Ger., *Tafelwage;* Ital., *Macchina da pesare;* Span., *Máquina para pesar.*

See Balance.

WHEEL AND AXLE. Fr., *Roue et Essieu;* Ger., *Rad und Achse;* Ital., *Asse nella ruota;* Span., *Rueda y eje.*

See Mechanical Powers.

WOOD-WORKING MACHINERY. Fr., *Machines à tailler le bois;* Ger., *Holzverarbeitungs-Maschinerie;* Ital., *Macchine da lavorare il legno;* Span., *Maquinaria para labrar madera.*

Next in rank to machine tools directed to metal working, machines for wood working are most important among those employed in industrial manufactures. As a material, wood enters largely into the construction and often forms the greater part of permanent structures, such as buildings and bridges, and in carriage manufacture, for both roads and railways; while for furniture wood is almost exclusively used. In ship-building, even in what are called iron ships, a large share of the material employed is wood. The elasticity of wood, and its rigidity compared with its weight, adapts it to many uses, for which no other material seems to be fitted; even the permanent way of railways rests on wood, whenever it can be obtained at a cost that will permit its use for the purpose. The number of persons engaged in wood manufacture, including joinery, ship-building, car and carriage making, and furniture manufacture, is greater in civilized countries than the number of those connected with the conversion of iron or textile substances, and with these two branches of industry excepted, wood manufacture is by far the most important branch of technical industry we have.

Wood, unlike metal, is not malleable, or ductile; it cannot be moulded or compressed into shape, but all forms made of wood are cut from blanks whose external dimensions will cover the finished object; bending, which is practised to some extent in the manufacture of light carriage-wheels and similar work, forms an exception to this rule, but is an inconsiderable part of the processes employed in wood converting.

The wood working begins with felling trees in the forest, an operation that is performed mainly by hand, all attempts thus far to construct felling machines for the purpose having proved unsuccessful, a result attributable to the necessary portability of such machines, the incessant adjustment required, and the danger of destruction from falling trees.

The first operation in wood working, after the logs are prepared, is forest sawing or slitting the logs into rectangular sections, called deals, scantling, plank or boards; deals, when sawed merely to reduce the timber to such dimensions as to allow it to be handled and transported; scantling, when the pieces are of a square section, or nearly so; planks, when sawed to final dimensions that exceed 1 in., and are less than 4 in. in thickness; and boards, when the thickness is 1 in. or less.

The machinery for lumber manufacture is called by the general name of mills in North America, a name that has no doubt been adopted from sawing machinery being in most cases operated in combination with machinery for grinding grain, each supplying the local wants of a neighbourhood, the sawing and grinding machinery being driven by the same motive power, and frequently both are erected in the same building.

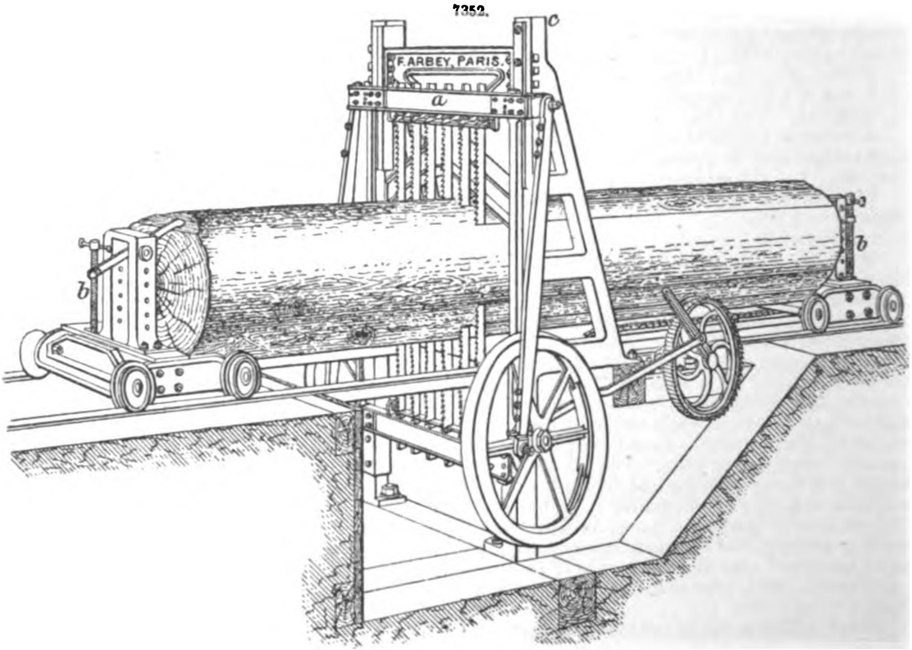
Lumber sawing machinery can be divided into three classes, consisting of reciprocating saws, rotary saws, and band saws. The extent to which the different classes are used being in the order in which they are named; reciprocating saws being most common in America, and almost exclusively used in Europe for lumber cutting. Fig. 7352 is a perspective elevation of a reciprocating lumber saw by Arbey, of Paris, arranged to receive a greater or less number of blades, as the nature of the work may require. *a* is a strong rectangular frame, in which the saws are strained and adjusted. This frame has a reciprocating movement of 20 to 30 in., imparted by the crank-wheel and connection seen in front. The log is mounted on the two carriages *b*, *b*, which are fed along by the spur-wheel and pawl gearing at the side, the feed movement being intermittent and consonant with the reciprocating motion of the sash or saw-frame *a*.

In some machines of this class rollers are used for feeding, so that the logs pass through continuously one after the other; such mills are called gang mills, and may be arranged with any number of saw-blades; the driving shaft can be placed on top of the main frame *c*, or a steam cylinder may be connected directly to the saw-frame *a*; the general principles of operation, however, remain the same.

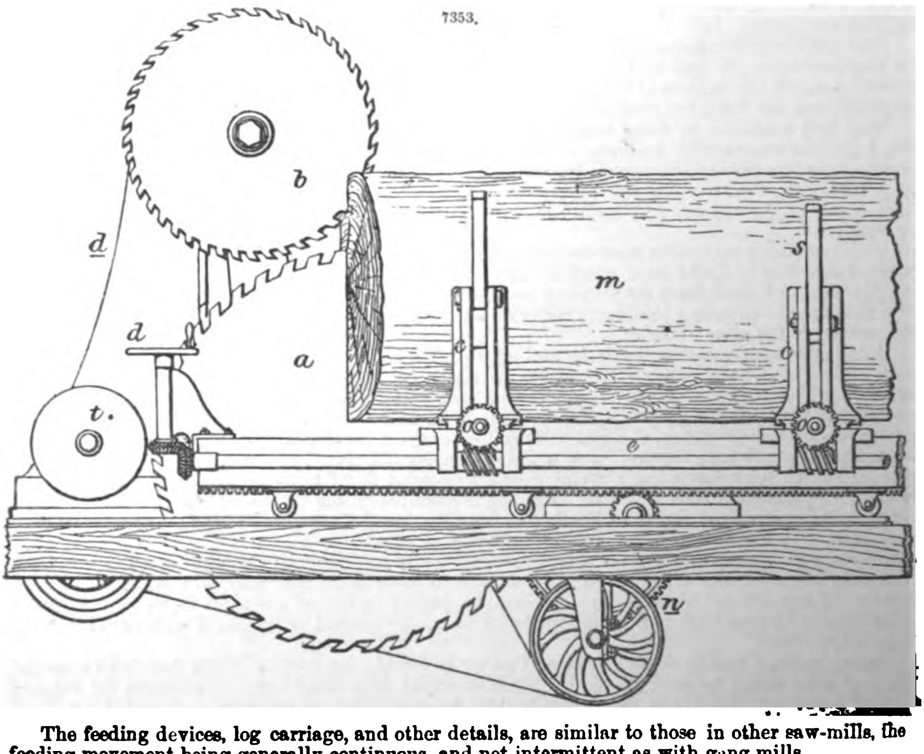
Muley mills, a variety of reciprocating lumber saw-mills, are used in North America for many kinds of work where accuracy of the lumber is an object, and sometimes by preference for regular lumber manufacture. These mills operate with an unstrained reciprocating saw supported by a light cross-head at each end, and by lateral guides at the sides of the blade, that come close to the top and bottom of the log, so that the saw is kept rigidly in place both in entering and leaving the wood. The saw-blades used in these muley mills are from 10 to 12 in. in width, and of unusual

thickness, in order to secure the required rigidity, and to sustain the strain of the up-stroke which falls on the saw-blade. The speed of these mills is from 300 to 400 strokes a minute, and their performance, aside from the kerf waste, is all that can be desired with a single blade.

7352.



7353.



The feeding devices, log carriage, and other details, are similar to those in other saw-mills, the feeding movement being generally continuous, and not intermittent as with gang mills.

Fig. 7353 is a timber sawing machine arranged with rotary saws, by Allen Ransome and Co.,

of London. Machines of this kind are extensively used in America, where the value of timber is not so great as in Europe, and the loss of the kerf by reason of the thicker saws required is not such an object. The saws not being supported by tension, and their rigidity being dependent upon the thickness of the saw-plate, when of large diameter should be made $\frac{1}{4}$ in. or more in thickness, which with a wide set, wastes from $\frac{5}{16}$ in. to $\frac{3}{8}$ in. at each cut. In Fig. 7353, *a* is the main saw, and *b* a top saw which is used when the depth of the timber exceeds the capacity of the saw *a*. The top saw *b* is supported on the cast-iron standard *d*, and is driven by a belt connecting the spindles of the two saws at the back of the standard *d*. E is a long reciprocating carriage carrying the log *m*; this carriage is operated by the gearing seen at *n*, which receives motion from the spindle of the saw *a*. The log *m* is adjusted laterally to the saws by the two standards *c*, *c*, operated by screws and the tangent-wheels *o*, *o*; *s*, *s*, are dogs or hooks that are driven into the log to prevent it from rolling; *t* is a flanged disc, technically called a spreader, that stands in line with the saws, and acts as a wedge to keep the pieces separated, and prevent them from clamping the saws.

7354.

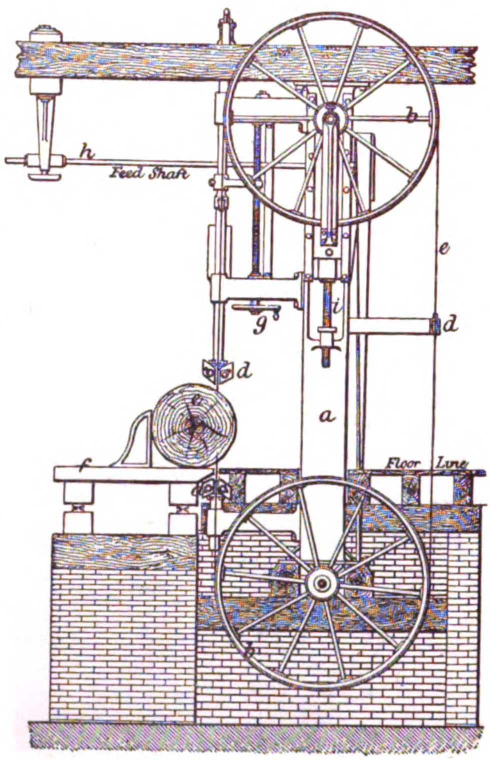
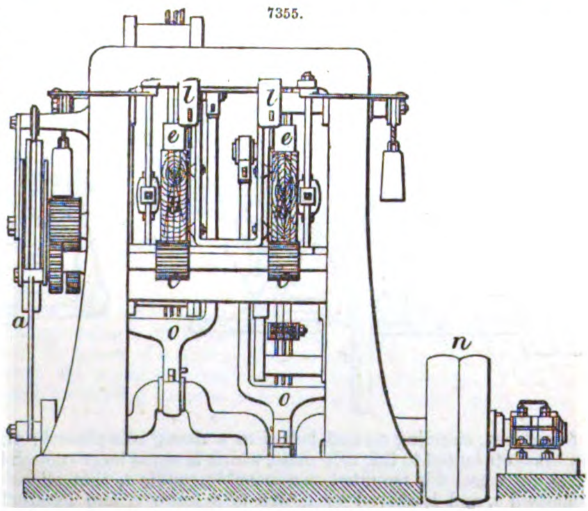


Fig. 7354 is a front elevation of a band sawing machine for sawing timber, by Richards, London, and Kelly, Philadelphia. *a* is a strong cast-iron column with which the wheels *b*, *b*, are connected; *e* is the saw; *d′*, *d*, *d*, are guides to steady and support the saw; *e*, the log being sawed; and *f*, a reciprocating carriage, similar in its action to the one last explained; the upper guide *d* is adjusted up or down by means of the hand-wheel *g* to suit the depth of the logs being sawed; *h* is a shaft transverse to the axis of the saw-wheels used for driving the feeding gearing, hauling in logs, or other purposes, as may be required. The top wheel has a vertical adjustment on the column *a* by means of the screw *i*, and rests on springs that equalize the tension of the saw-blade, and provide for the expansion and contraction of the saw caused by changes of temperature during the intervals of cutting. The machine as here arranged will receive saw-blades 50 ft. long to 6 in. wide.

Band saws waste but little kerf in lumber cutting, are capable of tension like reciprocating saws, and can be driven at a higher rate of speed than rotary saws. The experience in their use has, however, not been sufficient to meet the difficulties that arise in their operation, and the skill required to manage them is so great that their general employment, as in the case of large rotary saws, must be a work of time.

7355.

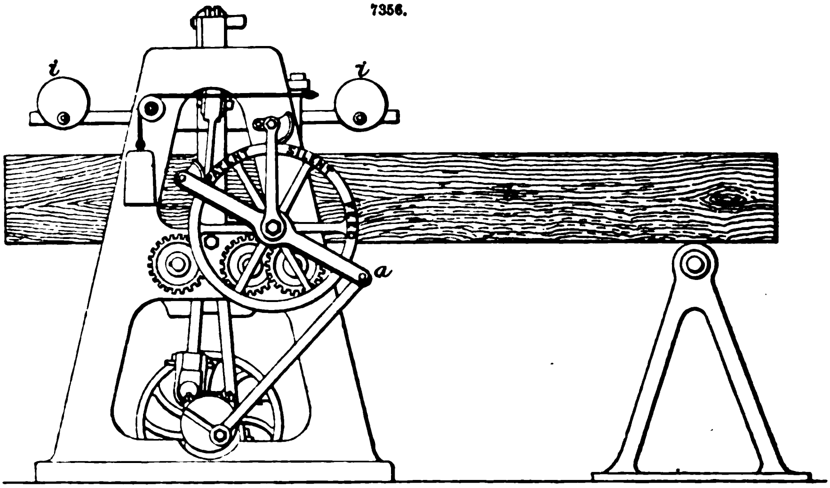


After timber cutting, the next process, for such lumber as requires to be reduced to less or more exact dimensions, is second sawing, or resawing, which is performed on machines that correspond in most respects to those used for timber cutting, except that the machines are not so heavy, and are driven at a higher rate of speed. Resawing is performed with reciprocating, rotary, and band saws, but more especially with reciprocating saws, where by the use of a large number of blades the aggregated cutting movement of the saws taken together may equal or even exceed that of rotary saws or band saws.

Figs. 7355, 7356, represent front and side elevations of a machine arranged for resawing or

second sawing, having two saw-frames and independent feeding devices, so that two deals or planks may be cut at the same time. The two frames are used with the further object of balancing each

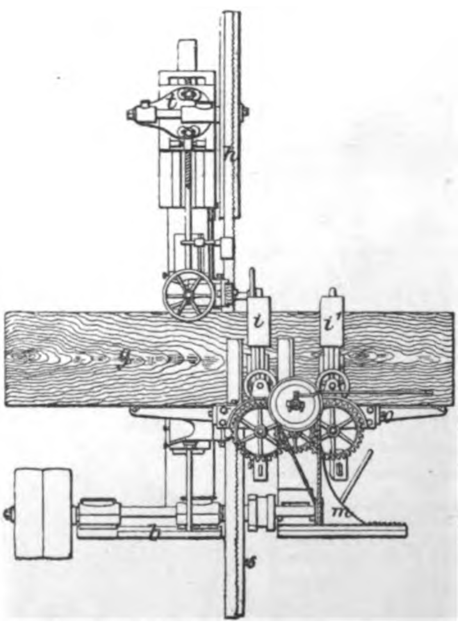
7356.



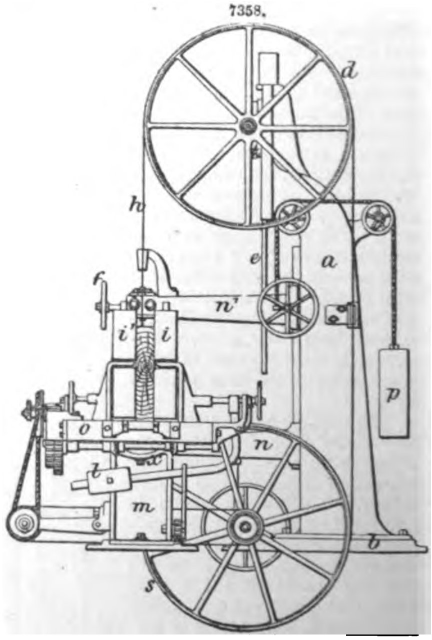
other, by having the cranks set opposite, and thus avoiding the jar and vibration that is inseparable from reciprocating machines. This is partially accomplished as the weight of the reciprocating parts approach one plane, and although the object sought in such a compounded machine is not fully attained, yet a great deal of the vibration is avoided. The feed in this machine is intermittent, and operated by the devices shown at *a*, *a*, which will be understood from Figs. 7355, 7356; *b* is a deal which is forced through the machine by the fluted rollers *c*, *c*; on the top of the deal there are pressure rollers *e*, *e*, held down by the levers and weights *i*, *i*; the crank-shaft is mounted in bearings connected with the main frame, and driven by the pulleys at *n*; *o*, *o*, are forked connections that pass up at each side of the saw-frames, and are attached to studs at the sides.

Figs. 7357, 7358, are of a band sawing machine arranged for resawing. The main standard *a* is

7357.



7358.



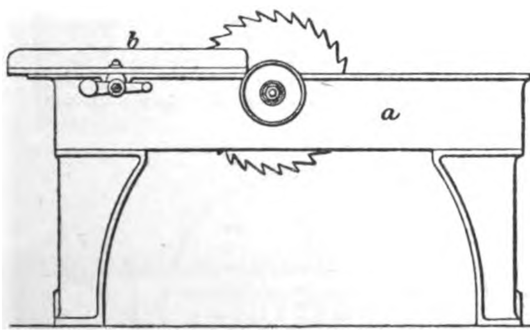
of cast iron, standing on and bolted to a strong sole-plate *b*; the shaft of the lower wheel *s* runs in brackets bolted to this sole-plate, which is made large enough to constitute a base for the machine. The top wheel *d* is mounted on a movable saddle *t*, that slides up and down upon the face of the standard *a*, and is moved by means of a screw *e*, and hand-wheel *f*, connected by bevel-gearing inside the arm or bracket *n*; *g* is a deal or plank fed to the saw *h* by means of the rolls *i*, *i*, which are driven by gearing beneath the platen *o*, and are pressed together by the lever and weight at *e*.

The feeding mechanism is all mounted on and supported by the stand *m*, which can be moved to or from the saw as required. These feeding devices and the table *o* on which they are mounted can be set at various angles by means of the concave seat seen at *x*. The saw-guides are carried on the two iron brackets *n'*, *n*, the top one having a vertical adjustment on the face of the column *a*, to accommodate lumber of various depths; *p* is a weight to counterbalance the top guide bracket *n*, so that it will stand at any point without fastening. The tension of the saw, as in the larger machine for timber cutting, falls on flexible springs. The saws used on this machine are 30 ft. long and 3 in. wide; they are given a cutting movement of 5000 ft. a minute.

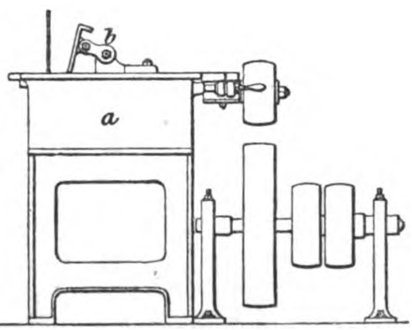
Circular saws are not much used for resawing, except when the pieces to be cut are thin enough to bend and allow a wedge-shaped saw to be employed, as in sawing veneers or scaleboards. A saw of parallel thickness, sufficiently rigid to perform resawing in dry lumber, would occasion a great waste by reason of the kerf; besides, circular saws are more difficult to operate in resawing than either reciprocating or band saws.

For cutting lumber into small pieces and to dimensions, as it is called, bench saws are used, consisting of a bench or frame with a flat top, and a rotary saw mounted as in Figs. 7359, 7360. *a* is the main frame which is, with the top, cast in one piece; *b* the gauge to guide the lumber and determine the thickness of the piece cut off; this gauge *b* is fastened to a stiff bar planed to fit into a dovetailed groove extending across the top of the main frame, the gauge being held by steel dowel-pins seen at *c*. The gauge *b* is arranged to be set at any angle up to 30° for cutting bent pieces; *d*, *d*, are details of the gauge *b*; *e* is the countershaft to increase motion from the line shafting, and to stop or start the machine by a shifting belt.

7359.



7360.



7361.

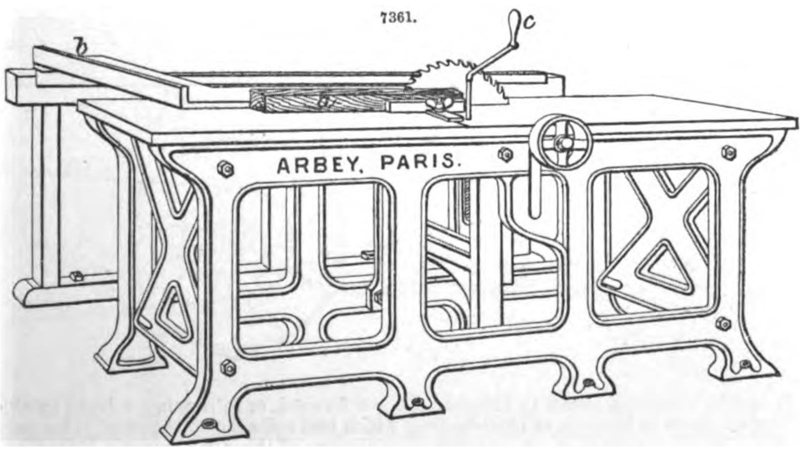


Fig. 7361 is a saw-bench arranged for both slitting and cross cutting; the gauge *a* is used in slitting, and can be removed while the traversing table is used for cross cutting. The saw with the mandrel and pulley is raised or lowered by means of a sliding frame *d*, operated by the winch *c*, so that the saw may be projected through the top of the bench to any height required, and within its capacity. This arrangement is used for cutting grooves or rebates, and in any case where the saw is to cut to a specific depth.

Machines for cross cutting lumber transverse to the fibre are generally distinct from machines used for slitting, and may be divided into two classes; one in which the saws are moved to the material, adapted to the heavier kinds of work, and the other when the wood is moved on carriages and the saws stationary.

Fig. 7362 shows a cross-cutting saw of the first class, with a movable saw *a*, which is mounted on a saddle that slides on the projecting standard *b*. This standard is arranged to adjust up or down upon the sole-plate *c*, as the diameter of the saw or the tension of the driving belt *d* may

require, the adjustment being made by the screw *e*. The carriage or saddle on which the saw-spindle is mounted is moved on the bracket *b* by means of the hand-wheel *f*, which is connected with a chain inside the standard or main frame *b*; *g* is a table for supporting the timber *h* that is to be cut. The top of this table is composed of a number of iron rollers to avoid friction and facilitate the adjustment of the timber. When the saw *a* is moved out or in, upon the bracket *b* the belt *d* traverses on the long drum *i*, the tension remaining the same at all points.

7362.

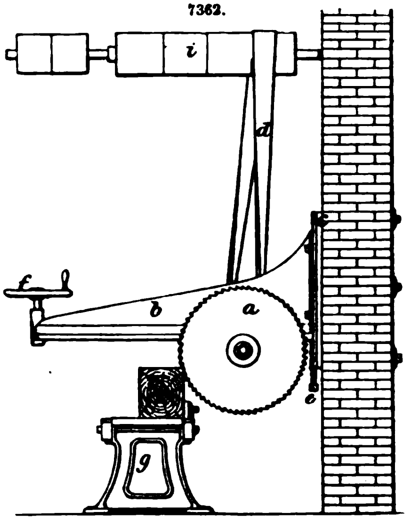
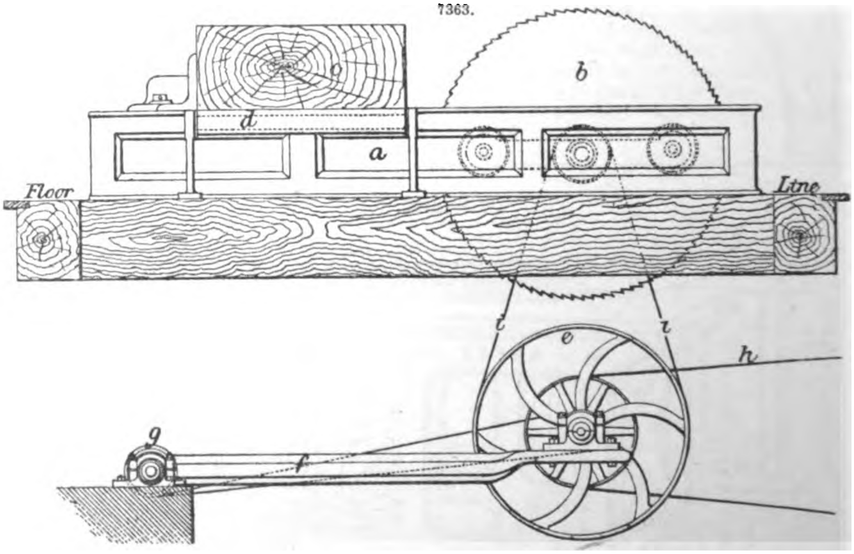


Fig. 7363 is another machine with a traversing saw arranged for cross cutting, the driving gearing being placed beneath the floor. *a* is the main frame of cast iron; *b* the saw, which is mounted on a carriage that moves on rollers inside the main frame; *c* is the wood to be cross cut, and *d* rollers on which it moves; *e* is the driving pulley hung in the radial swing frame *f*, pivoted at *g*. This frame *f* rises and falls as the saw is moved backward and forward on the frame *a*, and permits a regular tension of the vertical belt *i*; *h* is the driving belt by which power is communicated to the machine.

Various modifications of cross-cutting machines with traversing saws have been made, the diversity in their arrangement relating mainly to the means employed for communicating power to the saw-spindle. In all machines of this class that are driven by horizontal belts, or belts that run in the plane of the traversing motion of the saw, the driving strain of

7363.



the belt has to be resisted either in bringing the saw forward, or in running it back, an objection that is quite serious in the case of hand-feeding, which best suits the operation of these machines. With vertical belts or belts that run transversely to the line of the saw movement, this difficulty of belt resistance is avoided, and a steady action of the saw ensured.

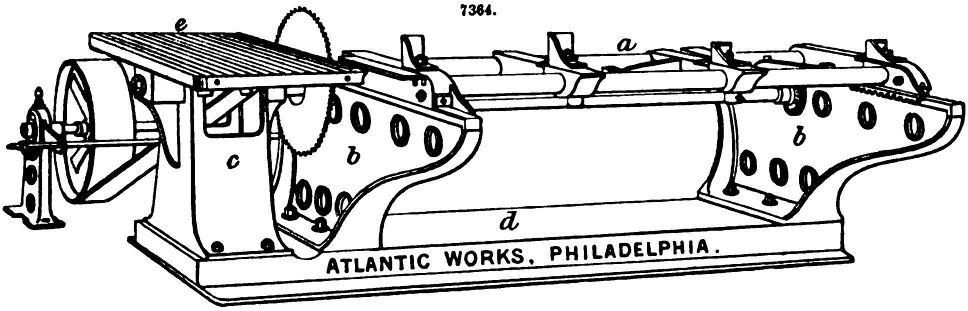
Fig. 7364 is what is called a carriage cut-off saw, the wood to be cut being traversed on the carriage *a*, which is mounted on rollers running on the top of the brackets *b*, *b*. The standard *c*, on which the saw-spindle is supported, and the brackets *b*, *b*, are bolted to a heavy sole-plate *d*, that keeps the parts of the machine in true adjustment; *e* is a small flat table to support the pieces cut from the lumber, the main part resting on the running table *a*.

It is obvious that small pieces of lumber, such as the parts of cabinet work, can be more readily moved and handled than a saw and mandrel, and that a machine arranged upon the plan of the one in Fig. 7362 is more convenient for ordinary uses than those arranged with a movement of the saw for feeding, as in the two machines just described.

When wood is to be cut in curved or irregular lines, saws of a narrow width must be used, the kerf allowing the course to be changed at pleasure, within certain limits; in this way curves can be cut whose radius does not exceed twice the width of the blade for saws to $\frac{1}{4}$ in. wide; for larger curves the width of the saws cannot exceed $\frac{1}{4}$ of the radius, unless the saws are made convex. This

class of sawing is usually termed sweep or scroll sawing for the heavier class of work, and fret sawing for the lighter or ornamental kinds.

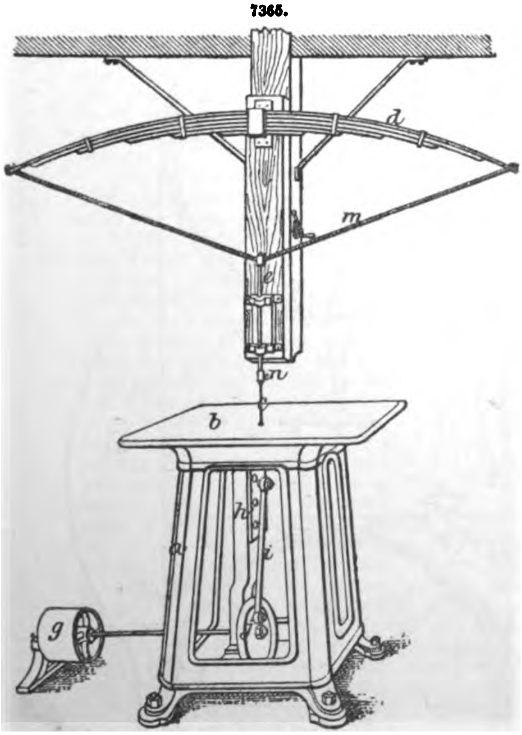
7364.



Scroll and fret sawing are performed with reciprocating saws and band saws; by reciprocating saws for perforated cutting, when the saws have to be passed through holes for what is called inside cutting, and by band saws for outside cutting, on the exterior of the pieces only.

Reciprocating saws for irregular lines consist of three modifications. Sash saws, when the saw is strained in a reciprocating frame used for heavy work; saws that are not strained and are supported like circular saws by the rigidity of the blades only; and saws strained by elastic or spring tension. In the second and third instances the machines are divided into two independent parts, connected only by the saw-blades, the object being to obtain a clear sweep for turning the lumber that is being cut. Saws strained in frames and used for sweep or scroll cutting are so analogous to reciprocating saws, already described, except as to size and strength, that no further description is required.

7365.



7366.

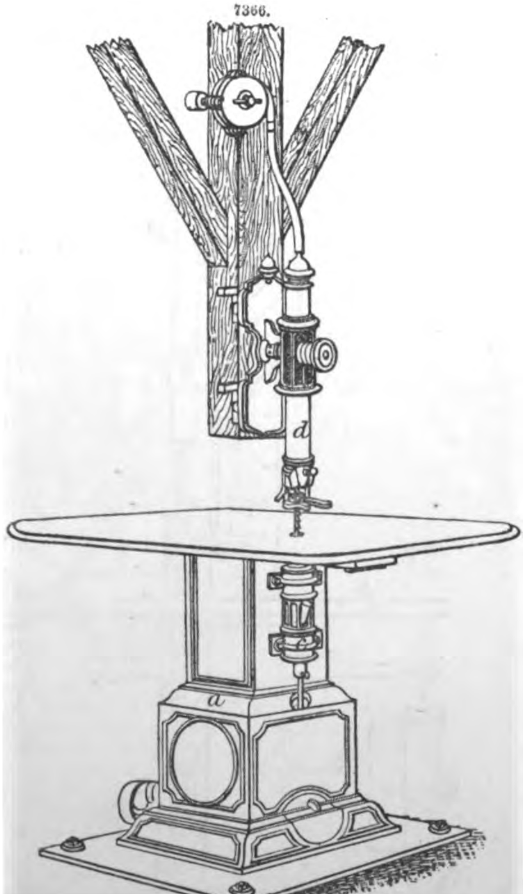


Fig. 7365 is a fret saw, of the spring-strained kind, made by F. Arbey, of Paris. *a* is the main frame, and *b* the platen or top, both of iron; *f* is the crank-wheel, and *g* the driving pulley; *i* is the

connection between the crank-wheel *f* and a sliding bar moving in guides beneath the table at *h*. The saw *e* is fastened to this slide beneath the table, and to a similar one *e* above the table.

This top sliding bar *e* is connected to the spring *d* by means of the flexible cord *m*. The light weight of the reciprocating parts permits a rapid motion of the saw, which can be for the same reason suddenly stopped, adapting the machine for perforated sawing. To pass the saw through the piece for inside work, the saw is disengaged at *n*, and the lumber passed over the top, or the saw may be loosed both above and below the table, and passed through holes in the lumber without lifting the piece.

7367.

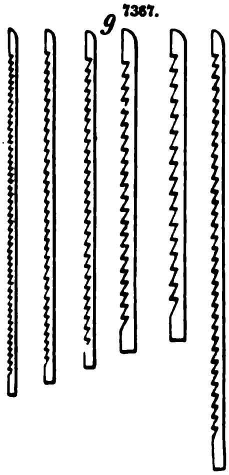
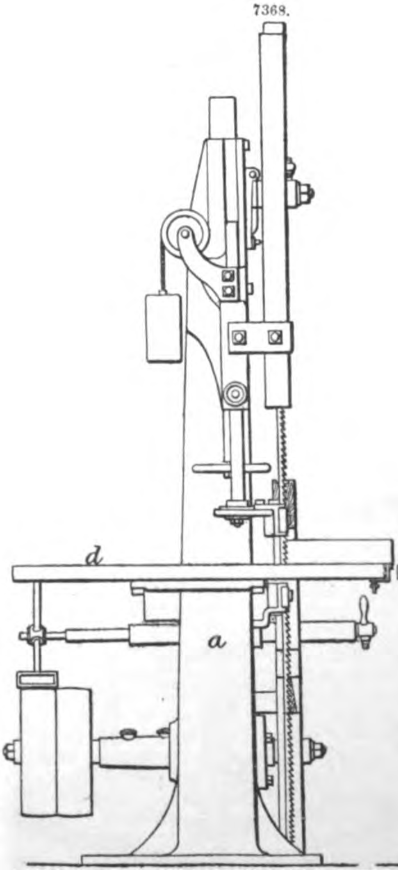


Fig. 7366 is a scroll sawing machine of a novel character, invented by J. Richards, of Philadelphia. In this machine the saw is not strained, but merely supported by means of anti-friction guides of hardened steel at its top that prevent it from turning, and give lateral and back support at the same time.

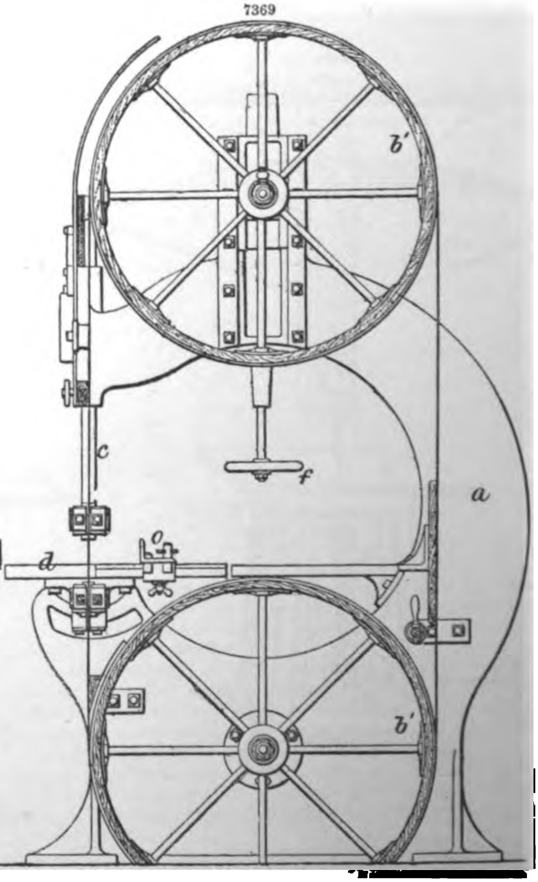
The principles upon which the machine is constructed are that the rate of cutting movement can be inversely as the weight of the reciprocating parts, and that while the cross-head beneath the table may be driven at a high speed, any weight attached to the top end of the saw limits the speed. The saw in this case, not having any weight attached to its top end, can be driven at any speed that the under gearing is capable of withstanding. 3000 of these machines have gone into use, in America mainly, but band saws being adapted to the same class of work, the reciprocating machines are not now so extensively used. These reciprocating machines, Figs. 7365, 7366, can be operated at a speed of from one to two thousand strokes a minute. *a* is the frame, cast hollow to receive the crank and shaft, which are placed inside for safety and to avoid the dust and débris from the saw. The crank and connection is of the ordinary construction, except that the joints are made with the care necessitated by the high speed at which they run.

The saws are rigidly fastened to a tubular stock or slide running in the bearings at *c*; between these bearings is a casing containing fibrous

7368.



7369



packing to maintain lubrication, the oil otherwise being rapidly absorbed by the saw-dust. Hardened steel guides are attached to the end of the sliding tube *d*; *f* is a small rotary fan for clearing the

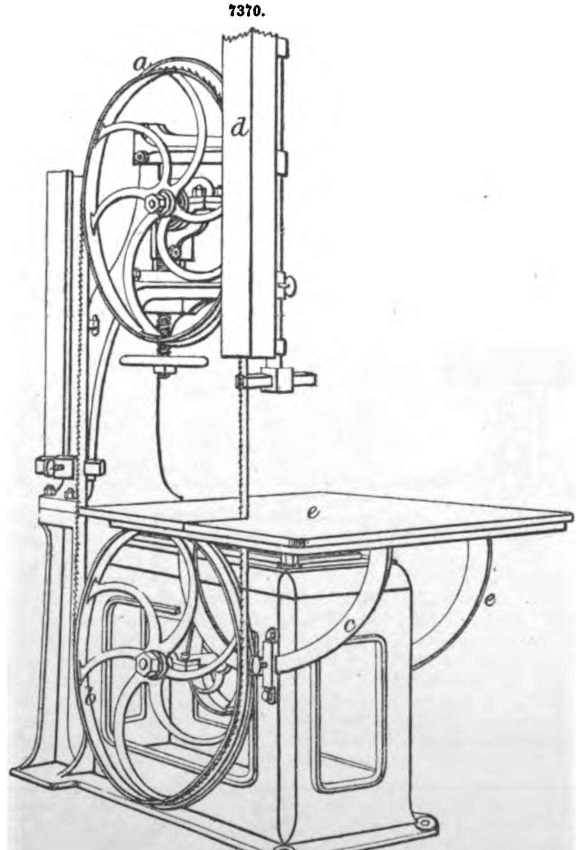
saw-dust from the work, connected by a flexible hose with the tubular guide-stem *d*, through which the air passes, escaping at *e*. *g*, Fig. 7367, shows the form of the saws used in this machine.

Band saws were invented in the year 1808, by Wm. Newberry, of London, but because of the difficulties met with in manufacturing the saw-blades and in joining them together, no regular use of the machines took place until forty years later. Band saws are extensively employed in sawing of all kinds, not only for curved lines, but also for slitting and for timber cutting, besides being applied to various uses in other branches of industry, such as splitting leather, sawing ivory, slate, and metal.

Band sawing machines consist essentially of two wheels, on which the saw is strained like a belt, guides to support the blades, and a flat table to move the material upon. Figs. 7368, 7369, are of a plain band sawing machine. The main frame *a* is cast in one piece, arranged to support the shafts of the top and bottom wheels *b'*, *b*, the guide-stem *c*, and the table *d*. The top wheel *b* is adjusted up or down by the hand-wheel *f* to regulate the tension and the variation in the length of the saw-blades; the table *d* moves on the quadrant beneath, to various angles for bevel sawing; *o* is an adjustable gauge for sawing parallel lines.

Fig. 7370, a band sawing machine. *a* the top or movable wheel, and *b* the driving wheel; *e* is the table, which is arranged to swing on a pivot, and is held by the quadrants *c*, *c*; *d* is a casing to guard against accidents occasioned by the saws breaking.

7370.



Sawing of all kinds, as an operation in wood conversion, has for its general object the dividing of pieces into parts, the separation of a mass into smaller pieces, but not the reducing such pieces to true dimensions. After dividing or sawing the timber or lumber, a further operation is required, called planing, which produces true dimensions, and smooths the surface to receive paint or varnish.

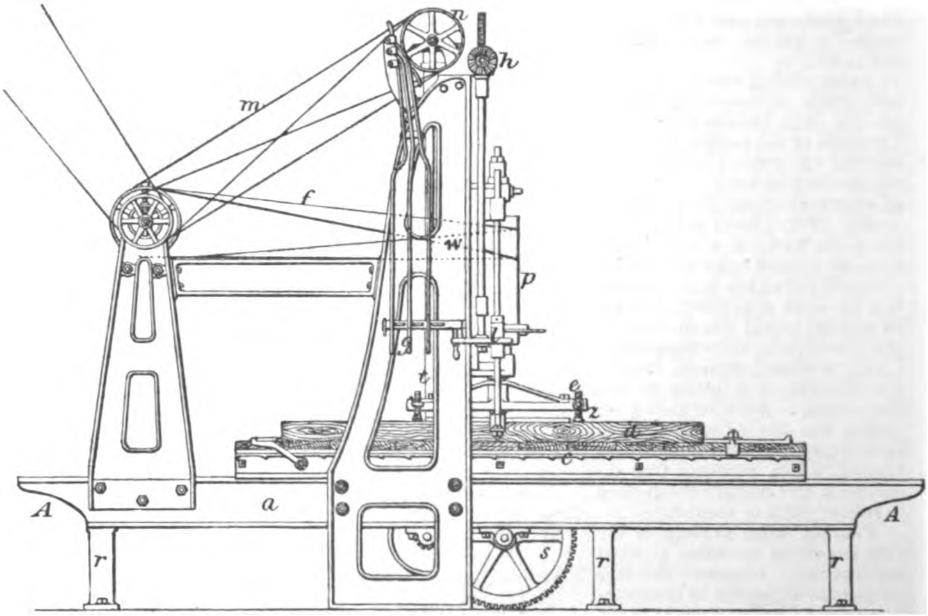
Planing, after sawing, is the next important operation in wood manufacture; machines for this purpose are all known by the general name of planing machines, but consist of three classes, that operate upon different principles. These machines consist in carriage, parallel, and surface planing machines, which will be successively noticed.

Fig. 7371 is an example of carriage planing machines, operating with traversing cutters, the plane of rotation being parallel to the face of the wood. *a* is a long frame supported on the stands *r*, *r*, *r*; *c* is a traversing carriage, on which the lumber *d* is carried beneath the cutter-head *e*; this cutter-head or cutter-bar *e* is mounted on a vertical spindle, and driven by the belt *f*, from the countershaft at *g*; *m* are belts that operate the feeding gearing at *s* by means of a vertical shaft *t* that is connected with the pulleys *n* at the top of the machine. There are three pairs of these feeding belts arranged to move the table *d* at various rates of speed, as the nature of the work may require, the rate of movement being controlled by the hand-levers at *j*. The cutter-spindle *p* is mounted in a frame that slides up and down on the front of the frame *w* to regulate the distance between the cutter *z* and the table *d*, the adjustment being made by the hand-wheel *l*, and the gearing and screw at *h*. The movement of the cutters exceeds 12,000 ft. a minute, the cutter-bar *e* being forged from fibrous iron to withstand the centrifugal strain incident to so great a speed.

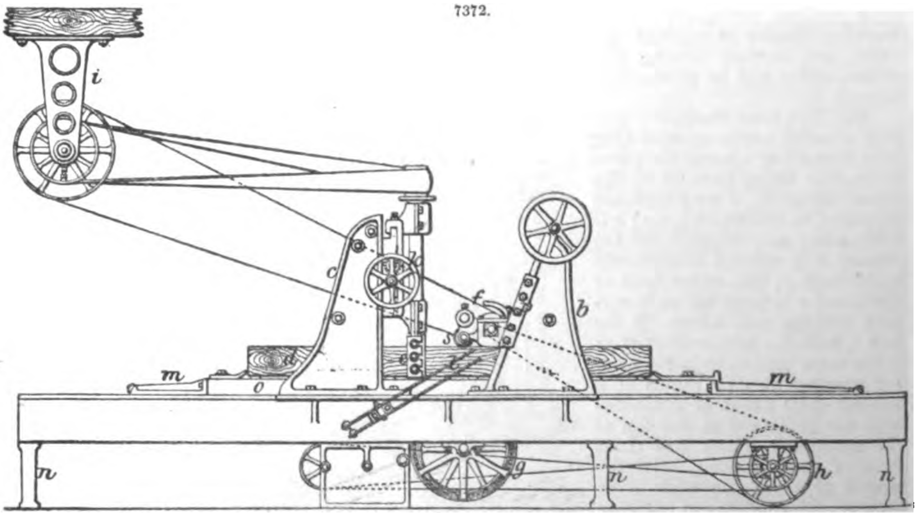
Fig. 7372 is a side view of another carriage planing machine arranged with cylinder cutters, the plane of rotation being at a right angle to the face of the wood, and with cutters to plane three sides of the lumber at the same time. As the aggregate length of the cutting edges can with machines of this kind be equal to three or more times the width of the lumber acted upon, it follows that the performance is more rapid, and the endurance of the cutters greater than when traversing cutters are employed, as in the machine last described. *a* is the main frame, supported on stands *r*, *r*, *r*; *o* a carriage that has a reciprocating movement given to it by a wire rope winding right and left upon the drum *g*, the ropes being fastened at the ends of the extension pieces *m*, *m*, which allow the wood *d* to pass entirely from under the cutters *f*. A rack can be employed on the under side

of the carriage, but does not produce so smooth a movement as the winding rope. The top cutters at *f* are carried in a strong frame *p*, that is adjusted up or down on the standards *b* by the hand-wheel *j*; a pressure roll at *s* bears on the top of the lumber to hold it firmly on the carriage.

7371.



7372.



The vertical or side cutters *e*, are supported on the standards *c*, and have a transverse adjustment across the machine to suit lumber of various widths; the feeding gearing at *g* is driven by belts from the countershaft *h*, and is arranged to give either a quick or a slow movement to the carriage *o*, the rate of movement being changed at will by the levers seen at *e*; *i* is the main countershaft from which all the cutters are driven.

In carriage planing the lumber is guided in a true line by means of the ways on which the carriages move, and the cutting performed with reference to the carriage movement instead of the shape of the material. All planing done in straight lines has of necessity to be performed upon this principle, and no machines except those with carriages are suited to the preparation of lumber that requires to be straight and out of wind, as it is called.

Parallel planing machines include machines that reduce lumber to a parallel thickness, either by passing it between cutters that are opposite to each other on different sides of the lumber, or when only one or two sides are planed, by passing the lumber between the cutter and stationary

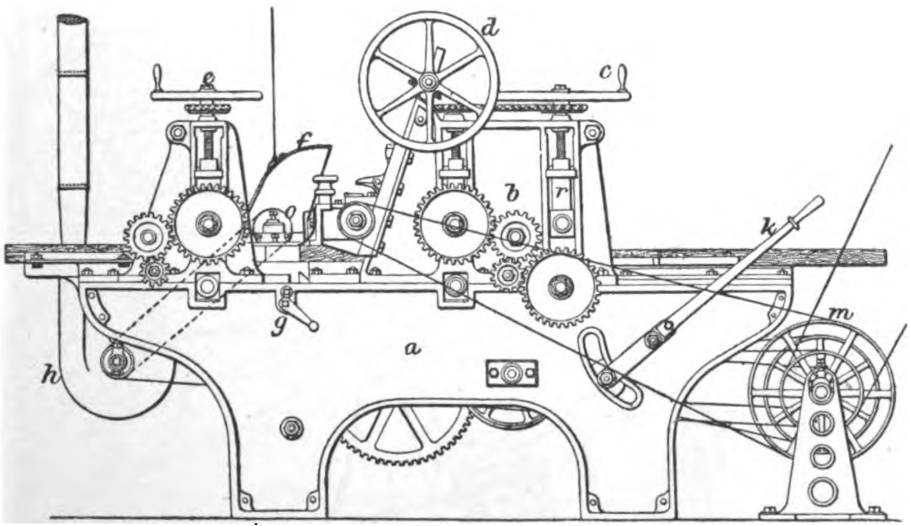
gauges or beds. The feed movement is continuous in machines of this class, the lumber being usually fed by means of rollers, that produce a regular forward movement in one direction. The effect produced in parallel planing is what the name indicates, that of giving parallel dimensions to the lumber, but not making it straight nor out of wind, as in the case of carriage planing.

The use of parallel planing machines is or ought to be confined to lumber that is flexible enough to be straightened by the feeding rollers and pressure bars in passing through the machine.

Parallel planing machines, as a class, are subdivided into planing and matching machines for manufacturing flooring, ceiling, or other lumber that is tongued and grooved; planing machines for dressing one or both sides of boards, technically known as surfacing machines; and moulding machines, adapted to the preparation of mouldings, and other pieces that have not flat surfaces. The difference between the first and third class of machines named being merely in capacity and size.

Fig. 7373 is a side view of a planing and matching machine, arranged to operate on three or four sides of the lumber at the same time.

7373.



The lumber is forced through the machine by three pairs of feeding rolls, that are connected by expanding gearing, and are pressed down upon the lumber by springs *r*, of vulcanized india-rubber. *a* is the main frame, on which is bolted the housing *b*, which carries the first pair of feeding rolls, the top cutters, and the pressure bars or rollers; the top rolls are adjusted simultaneously by means of the hand-wheel *c*. The top cutters are adjusted up or down by the hand-wheel *d*; the rear, or clearing rolls, are adjusted by the wheel *e*. The vertical, or side cutters, are seen at *o*, under the hood *f*, for collecting shavings and dust by pneumatic suction. These side cutters have a traversing adjustment across the machine, and are moved by the crank at *g*. The shavings are collected in the hood *f*, and are then drawn into the fan at *h*, and expelled through the pipe *i*, being carried to a stoke room or elsewhere, as required. The feed movement is stopped or started by means of the lever *k*; *m* is the countershaft which drives all the cutters and the exhausting fan at *h*. When the machine is used for planing but one side of wide lumber, the side cutters at *o* are easily removed, and the lumber allowed to pass over the top of the spindles, when the distance between is not enough to accommodate the width of the lumber.

As this class of planing machines is more extensively used than any other, especially in the preparation of building material, and as no dimensions have been given in describing other machines for planing, it may be a matter of interest, and convey a general idea of the proportions in such planing machines, to note the following dimensions in connection with Fig. 7373;—

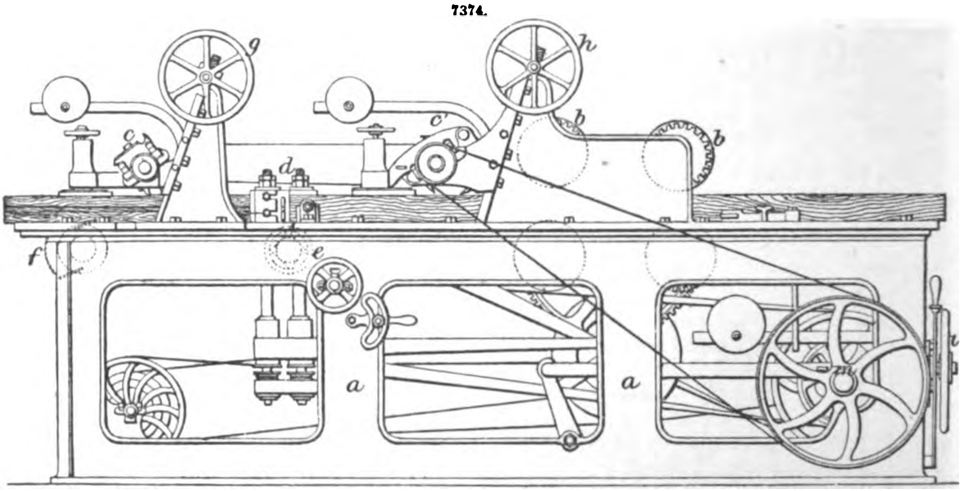
The machine receives lumber for surfacing only, to 24 × 5 in.; planes, tongues, and grooves to 14 × 5 in. Main cutter-block, 6½ in. diameter, 24 in. long, 3 cutters; side cutter-blocks, 6½ in. diameter. Aggregated width of belts for driving cutter-spindles, 17 in. Rotary movement of cutters, 6750 ft. a minute. Aggregate of cutter movement for each block, 20,250 ft. a minute. Number of revolutions of cutter-spindles, 4000 a minute. Top cutter-spindle, 2 in. diameter, steel. Side cutter-spindles, steel, 1½ in. diameter. Rate of feed from 40 to 60 ft. a minute. The wheels of the expansion gearing are made of steel throughout.

Fig. 7374 is of a planing machine for moulding and matching, arranged with six cutting spindles and two pairs of feeding rolls. *a a* is the main frame; *b*, *b*, feeding rollers; *c*, c^1, top cutters; *d*, side cutters. There are also bottom cutters at *e* and *f*. The top cutters are adjusted up and down by means of the hand-wheels *g* and *h*; the top feeding rolls are raised or lowered by the hand-wheel *i*.

The top cutter *c'* is intended for straight cutters that produce a flat surface, which can then be

moulded by the second top cutter c; the spindle at f can be arranged with circular saws, to divide the lumber into several pieces after it has been planed. All the cutter-spindles are driven from the shaft at m. The feeding rollers b, b', are hung in swing-frames that are pivoted on the axis of a shaft, from which they are driven, and rise and fall in a curve described from that centre.

7374.



7375.

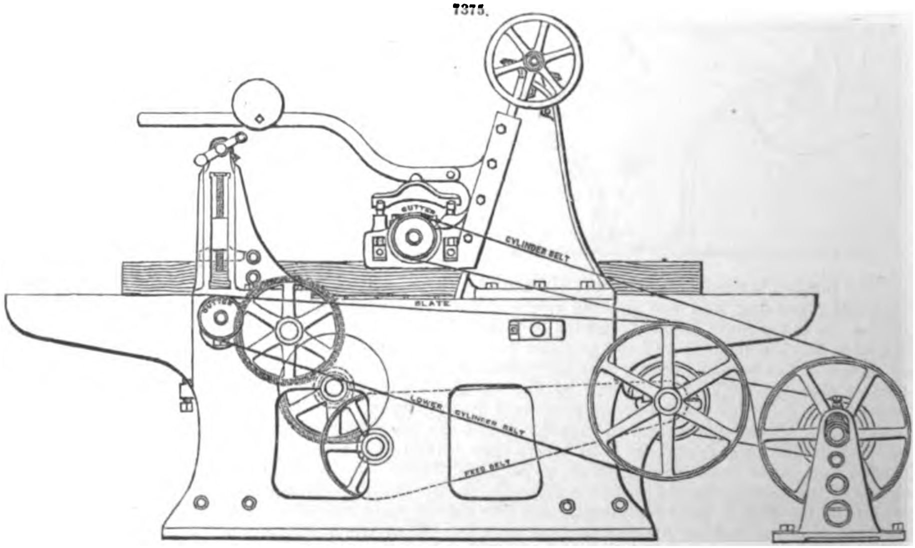
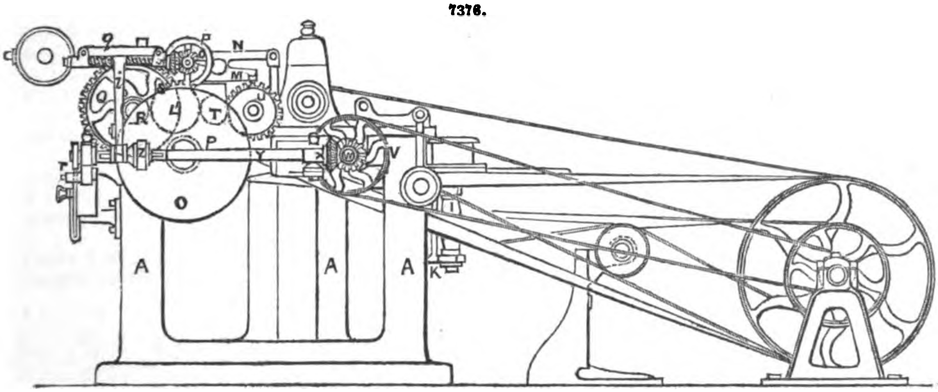


Fig. 7375 is a parallel planing machine to plane on one or two sides, the top and bottom of such lumber as is not required to be reduced to a width at the same time. The feeding movement of the lumber is in this machine produced by means of an endless revolving apron or bed, composed of bars linked together, that are carried on the two axes at a and c, and move like a belt beneath the top cutters at d. These bars being corrugated, and presenting a flat surface of two or more feet in length under the cutters, carry the lumber forward with great force. The bottom cutter $a\ e$ is driven from the shaft f, which is in turn driven by the frictional contact of the belt g that gives motion to the top cutters d; h is a dead bar opposite the bottom cutters to hold the lumber i at that point when being planed on the under side. The saddle m, on which the top cutters and pressure rollers are mounted, is adjusted up or down on the standards n, as in the other machines noticed. These machines were invented about 1850 by an American named Farrar, and were designed to avoid the celebrated Woodworth patents, that for a long time controlled and hampered the progress of wood planing in the United States. The chain-bed planer, however, achieved more than its inventor had expected, and thousands of machines have been made upon this plan, which for some purposes has advantages over roller feeding machines.

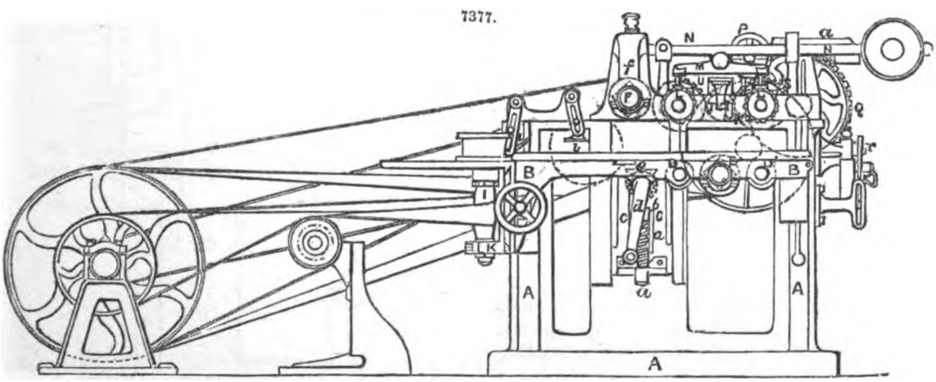
Figs. 7376, 7377, show a moulding planing machine arranged to act upon all four sides of the lumber at the same time, producing various profiles, as the shape of the cutters may determine.

A is the framing; B a table outside the framing; this table is free to rise and fall to the extent of about 9 in. more or less. C a projecting leg from the bottom of the table furnished with dove-

7376.



7377.



tails which slide in grooves in the frame of the machine. Up-and-down motion is imparted to the table through the screw *a* working in a nut *b* fixed to the frame A; the screw is driven by the toothed wheel *c* through the crank-handle *d*, the wheel *c* driving a mitre-wheel *e* keyed on to the top of the screw. The table B carries the bottom rollers D, D, and the revolving bottom cutter-shaft and cutters E; F is the top cutter-shaft and cutters extending beyond the frame of the machine and over the table B; the outer end of this top cutter-shaft revolves in a bearing carried by the projecting arm *f*. The table is formed with an aperture to allow of the working of the vertical cutters; these cutters are carried on shafts to which pulleys I, I, are keyed; the pulleys and shafts are connected to plates K, themselves attached by bolts to plates sliding in dovetails on the table B. Curved slots are made in the plates K, through which studs pass to allow of the plates being fixed at any inclination required in order to cause the cutters to cut the wood on either or both sides to the angle required. L, L^1, are the feed-rollers; M is a beam with two depending legs terminating at bottom in a point; each of these points enters a V-recess on the top of the bearings of the feed-rollers. This beam M is free to move on a centre to allow the rollers to oscillate when the wood is first fed on to the table. N is a weighted beam pressing on the beam M; *k* is a roller carried by a bracket *l*, the top of which works in a box, and is continually pressed upon by a spiral or other spring; the object of this roller is to keep the wood in contact with the bottom cutter, and to steady it under the action of that cutter.

In the feed arrangements, O is the disc-wheel; P a pinion on the boss of the disc-wheel; this pinion gears into the toothed wheel Q, on the boss of which there is another pinion R, which drives the wheel S keyed on the shaft of the feed-roller L^1. T an intermediate pinion for driving the wheel U on the shaft of the other feed-roller L; V a pulley driven by a belt; it carries a mitre-wheel W in gear with another mitre-wheel X on the shaft Y; Z a clothed friction pulley free to travel to and fro on a feather on the shaft Y when moved by an arm l^1. On one end of this screw arm is fastened a mitre-wheel which is geared into by another mitre-wheel *o* on a shaft which is moved by a hand-wheel *p*. The arm l^1 carries at top a pointer, not seen in the drawing, to indicate on an index plate *q*, the back of which is shown, the rate at which the wood is driven through the machine by the feed-rollers.

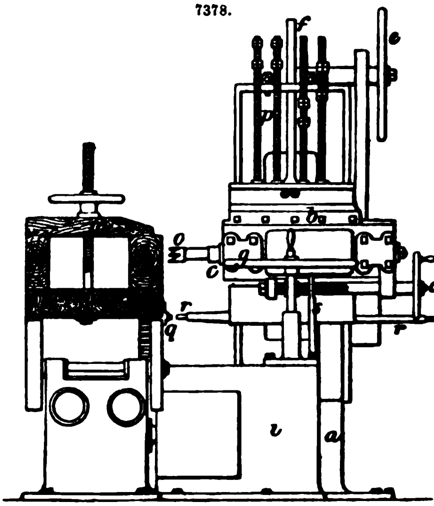
The operations of sawing and planing wood that the machines thus far noticed are directed to, may be called general operations, through which nearly all lumber used for every purpose must pass. After planing, operations in woodwork become diversified; the material is then bored, mortised, tenoned, or shaped into various forms for ornament or special uses.

Mortising machinery consists of rotary and reciprocating machines; in the first the wood is cut away by rotary tools that have also a vibratory or reciprocating motion, to produce oblong recesses the length of the mortise. Rotary mortising machines are extensively used in France and in England, where they are applied to all kinds of work, mainly because mortising can be performed in this manner on machines that may be also used for other purposes; but in the United States and Sweden, where in wood manufactures the division of labour is carried further, and where each operation requires a separate machine, rotary mortising machines are only applied to the heaviest class of work when the material is too heavy to be handled for reciprocating machines, when the material can be bored for bolts, or faced at the same time that the mortising is performed, and when mortising such pieces as cannot be held firmly enough to resist the shock of reciprocating machines, especially the parts of chairs that are cylindrical or irregular in form.

In the largest rotary mortising machines used for mortising the framing of railway carriages, bridge timbers, and so on, the reciprocating motion is given to the cutters, which are usually of a diameter equal to the width or one-half the width of the mortise, so that one or two movements will complete each operation.

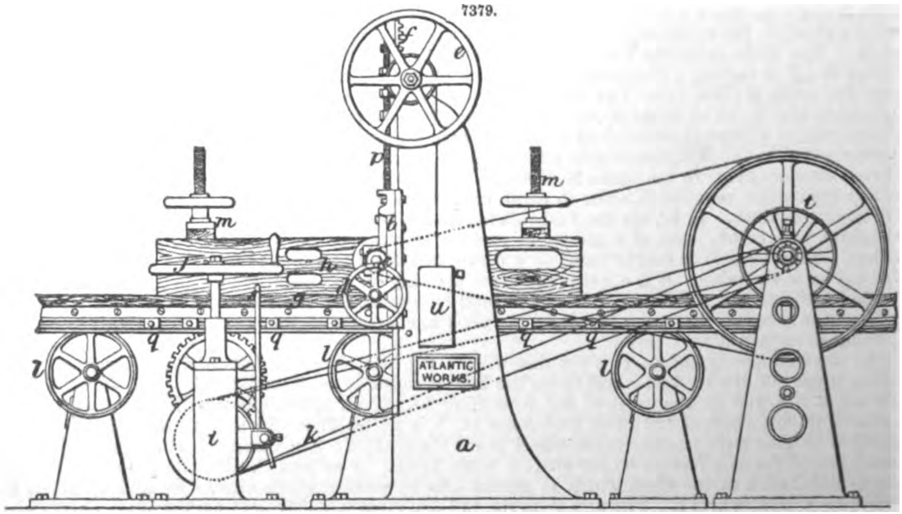
Figs. 7378, 7379, are elevations of a rotary mortising machine. Fig. 7378 is a front view; Fig. 7379 a side view. *a* is a strong standard, *b* a saddle fitted to move up and down on planed guides on the front; the spindle *c* is mounted in a second saddle that has a transverse movement across the saddle *b*, and is moved by the hand-wheel and screw at *d*.

7378.



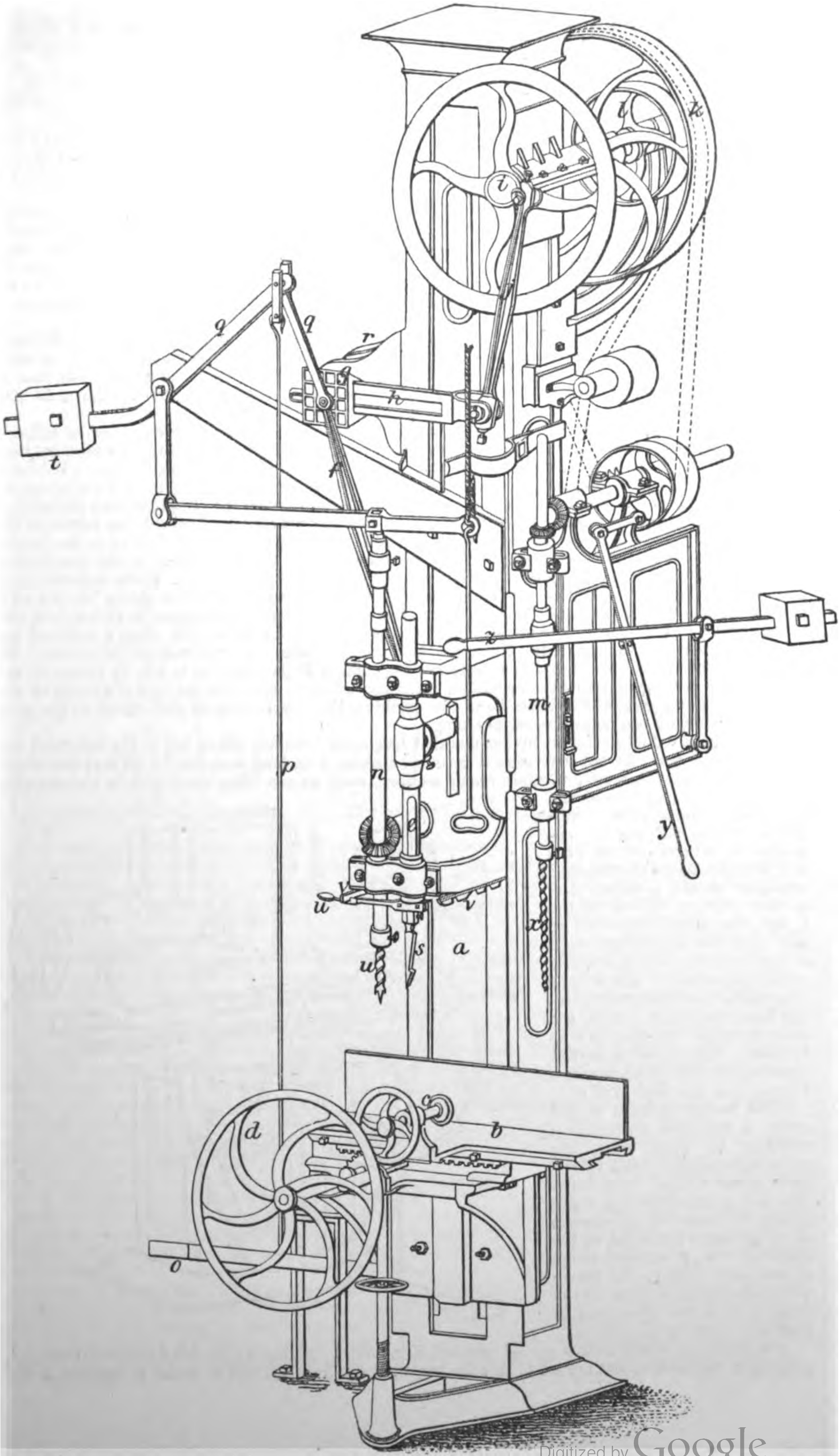
The saddle *b* is moved up and down on the front of the column *a* by means of the wheel *e*, and the rack and pinion *f*; *g* is a long carriage on which the timber *h* to be mortised is placed. This carriage *g* is moved either by hand or power by means of the gearing in the casing *i*, operated by the hand-wheel *j* or the belts *k*, as the motion of the work demands. The carriage is supported on large rollers *l*, *l*, *l*, to avoid friction and permit hand movement, which is essential in many operations. The wood *h* is held by clamps *m*, and is placed on the carriage in such a way that stops determine the position of the holes or mortises, which therefore require no laying out, their position being determined by stops or gauges *q*, *q*, *q*, when the timber is properly adjusted. The vertical or lateral movement of the cutter *o* is regulated by the four stop-rods *p*, each provided with collars to determine the movement of the saddle *b*, stopping at eight positions, and giving dimensions and lateral position to the mortises accordingly.

7379.



The length of mortises and the distance between them is also determined by the stops *q* that slide and are fastened in a groove on the front of the table *b*; these stops *q* come in contact with the stop-rod *r* that is operated by hand from the back of the machine. By setting these stops *q* and the vertical stops *p* to suit the number and position of the mortise, any number of pieces can be mortised or bored precisely alike. The power movement of the table, which is 100 ft. a minute

7380.



each way, is controlled by the lever *s*, which with the wheels *d, j, e*, and the stop-rod *r*, are all within reach and control of the operator; *t* is the countershaft from which motion is given to the cutter-spindle and the traversing gearing at *i*; *u* is a counterweight to balance the saddle *b* and spindle *o*.

Small rotary mortising machines have both rotary and reciprocating motion of the cutters, the wood remaining fixed, the rotary motion being usually 7500 revolutions a minute, and the reciprocating motion 400 strokes a minute.

Reciprocating mortising machines are constructed under various modifications suited to heavy or light work, and for deep or shallow mortises; the mechanism and movements being, however, much the same in all machines, consisting essentially in a crank-shaft, a chisel-bar, and tables or carriages to present and move the material.

The greatest distinction in such machines is between those that have a chisel feed, where the chisel and chisel-bar, in addition to a reciprocating motion, has also a graduated feed movement, and machines that are arranged with a feed movement of the table or carriage, that raises the wood to receive the action of the chisel. In the first, as the chisel is fed to the wood, or down into the mortise, it is evident that the relative position of the crank and chisel has to be changed to the extent of the feed movement; in other words, there has to be either an elongation or a contraction of the connections between the chisel and the crank.

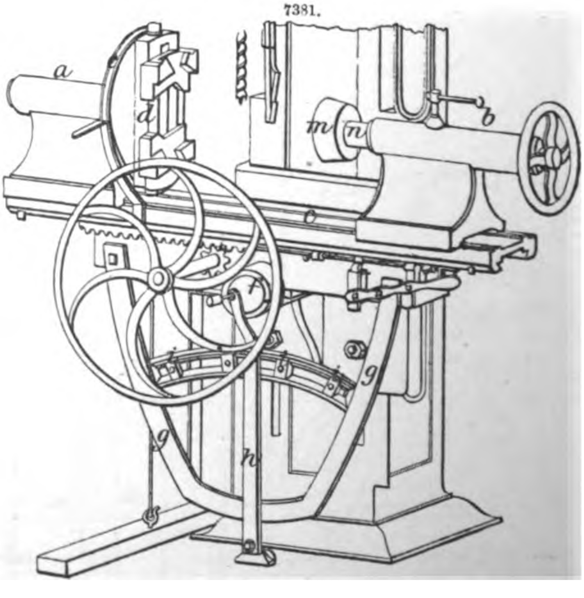
Fig. 7380 is a perspective elevation of a reciprocating mortising machine, with a graduated stroke, by Lane and Bodley, of Cincinnati. The machine was invented by Thomas Guild, in the year 1852.

The machine has been selected as an example, because of the long test that it has had in all countries, and from the fact that there were in 1873 more than 3000 such machines in use, including those arranged for wheel-hubs and other special purposes.

Fig. 7380 is what is termed a railway-car mortising machine, because of an extra boring spindle, and the nature of the table; the chisel-bar and reciprocating parts being the same on all machines, except as to the range of the stroke, which varies from 3 to 10 in. *a* is the main column; *b* the table on which the material is supported; *c* is a clamping screw to hold the material; and *d* a wheel for traversing the table *b*. *e* is the chisel-bar; *f* the connection between the chisel-bar and the sliding block *g*; *h* is a pivoted vibrating lever that receives motion from the crank-wheel *i* by means of the connection *j*; *l* is the driving pulley where the power is applied; and *k* a pulley to drive the boring spindle *m*, and also the boring spindle *n*, on the other side of the machine; *o* is the treadle that puts the chisel-bar in motion and controls the stroke by means of the rod *p*, which extends up to and operates the toggle-links *q, q*. The vibrating lever *h* being pivoted in a strong bearing at *r*, the sliding block *g*, when in the position shown, has only an oscillating motion on this axis *r*, and the connection *f* and chisel-bar *e* are still; but by depressing the treadle *o* the block *q* is forced out upon the lever *h* by means of the links *q, q*, and the chisel-bar *e* is gradually set in motion. By this action the chisel *s* has not only a reciprocating motion imparted to it, but is, by reason of the connection *f* coming into a vertical position, *fed downward at the same time*, so that the depth of the mortise cut may equal the whole stroke of the machine, the chisel rising at each stroke to the *same position on the up-stroke*, regardless of its range.

Attention is called to this feature as one that has, more than any other, led to the extended use of these machines. To cut a mortise 9 in. deep, a crank 5 in. long is sufficient, so that the whole stroke is utilized; but with variable crank motions, such as are often employed in constructing mortising machines, the stroke has to be at least twice the depth of the mortise, with one or more inches added for clearance. This will be understood by noting that when the block *g* is drawn back to the position shown in the figure, the chisel *s* is raised to the top of the stroke, by reason of the diagonal position assumed by the connection *f*. The weight *t* stops the chisel motion by drawing back the block *q* upon the lever *h*, when the treadle *o* is relieved. The chisel is turned from right to left by the handle *u* locking into the catches at *v*.

7381.



The boring spindle *n* and auger *w* are used for starting mortises in hard wood, the spindle remaining fixed in the same plane as the chisel-bar *e*. The boring spindle *m* and auger *x* have a transverse adjustment of 16 in. across the table or the material, also a vertical range of the same length; the transverse adjustment is given by the lever *y*, and the downward or feed movement by the lever *z*.

For mortising wheel-hubs, a special carriage, Fig. 7381, is employed; the head and tail stocks *a, b*, slide upon the table *e*, and are set to suit the length of the hub, one end of which is fastened in the

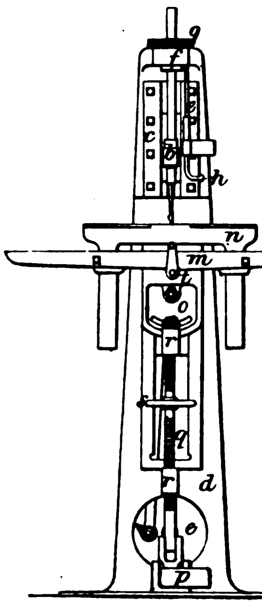
chuck d, provided with a plate e, divided like the disc of a wheel-cutting machine, with spaces for the position and number of the mortises; the taper of the mortise and the flare of the spokes are provided for by swinging the carriage e upon the pivot f by means of the quadrant g and the lever h, which has stops i, i, i, that are set to suit the kind of wheel-hub that is being mortised.

The disc-pivot m is loose upon the poppet-spindle n, and revolves with the hub. Two hundred hubs of medium size can be mortised on one of these machines in ten hours with an accuracy that is not attainable by hand.

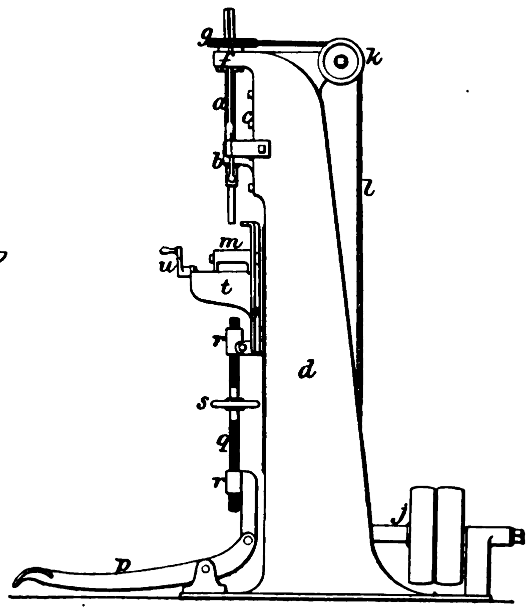
The tendency in wood manufacturing at the present time is to the use of rotary mortising machinery for nearly all classes of work that have heretofore required the heavier reciprocating machines; and there is no doubt that when there has been the same amount of attention given to the improvement of rotary as there has been to reciprocating mortising machines, there will be still more of them used.

Reciprocating machines that have a positive connection between the chisel and crank, and are arranged to feed the lumber up to the chisel, as in Figs. 7382, 7383, are simple in construction and

7382.



7383.



free from many objections that apply to those with a chisel feed. The chisel-bar a is cylindrical, with a bearing in the driver b. This slide or driver b is connected to the crank-wheel e by a rod or connection that passes up on the inside of the main standard d. The driver b moves in the guides c on the front of the standard d, moving the chisel-bar a up and down through the top bearing at f. Surrounding the bar a, in this top bearing f, is a shell connected with the grooved pulley g, through which the bar a plays freely, but is held from turning by means of a feather. On the under side of the pulley g are two stops that come in contact with the rod h. The belt i passes around the pulley g, over the idle pulleys, and around the driving shaft at j. This belt maintains a constant torsional strain upon the pulley g, which, as soon as the rod h is drawn down, will commence to rotate; but by releasing this stop-rod h instantly, the pulley g makes but a half rotation, until the stops on its under side arrest its movement, the belt i serving to both turn the pulley g and the chisel-bar, and to hold them firmly after being stopped by the rod h. By this arrangement the chisel is instantly turned to the right or to the left to complete both ends of the mortise by the operator simply depressing the bent handle at h with his hand.

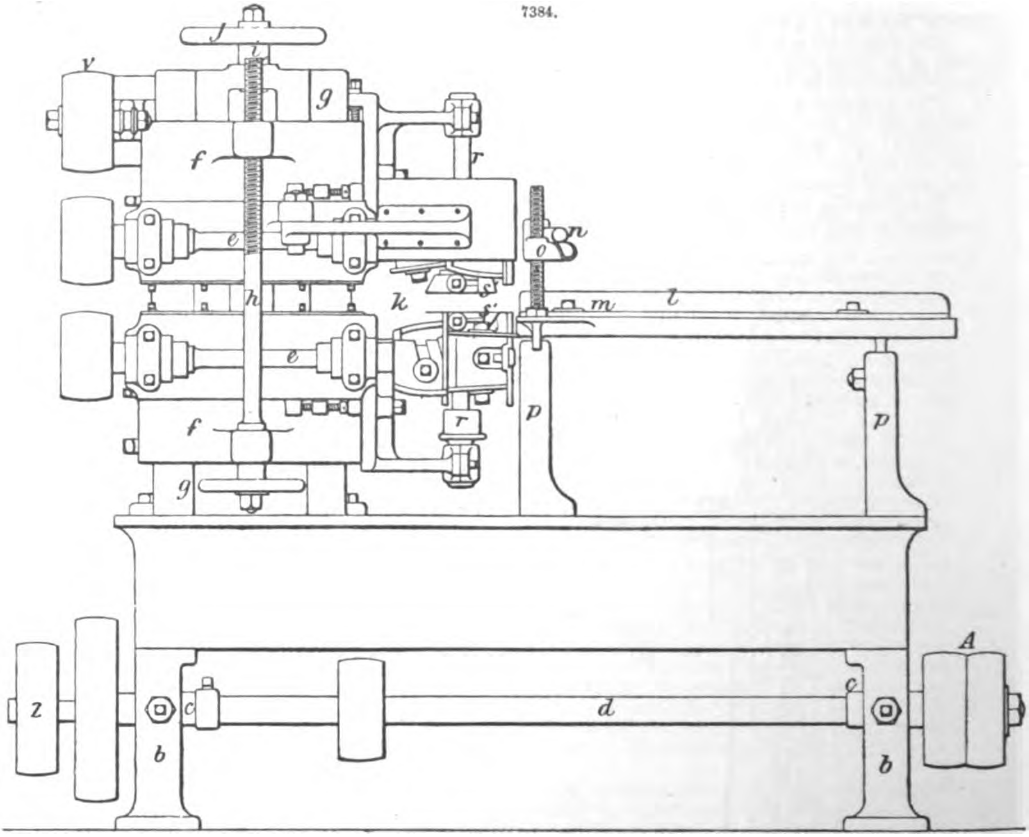
The wood to be mortised is placed upon the table m, and is held down by the guard n, which is set at various heights to suit the depth of the piece. The table m, with a sliding saddle o, is raised by the treadle and the screw g. This screw has right and left hand threads fitting into the pivoted bearings r, r, and serves to adjust the height of the table m by turning the hand-wheel s. The table m is moved out or in upon the bracket t by the winch u. The bracket is pivoted so as to be set at various angles for making diagonal mortises.

Machines for cutting tenons in woodwork are constructed under two general modifications, one with the cutter-spindles parallel to the tenons, and the other with the cutter-spindles transverse to the tenons. Figs. 7384, 7385, are of one of the first kind of tenoning machine, and Figs. 7386, 7387, one of the second.

Referring to Figs. 7384, 7385, a is the main frame; b supports which also carry the bearings c of the driving shaft d; e, e, are the main cutter-spindles, mounted on the movable saddles f, f, which are adjusted up and down upon the stand g by means of the screws h and i, the top saddle f being raised or lowered by the screw i and hand-wheel j, and the two saddles separated or brought together by the screw h; thereby gauging the thickness of the tenon between the cutter-heads at

k, or its position on the piece, by raising or lowering both saddles *f* and *f* without changing their relative position.

7384.



The piece to be cut is placed on the carriage *l* against the guard *m*, and is held by the clamping lever *n*, which is, with the handle *o*, grasped by the operator's hand. The carriage *l* is mounted on rollers supported in the two brackets *p*, *p*; this allows it to move freely by hand without the aid of power-feeding mechanism, which is not suitable for the operation, the feed requiring to be fast at some points, slow at others, and at all times regulated by the perception and skill of the operator.

r, *r*, are coping or scribing spindles, for shaping the shoulders of tenons for moulded pieces, the cutters *s'*, *s'*, rotating in a plane parallel to the face of the tenon. These spindles receive motion from the vertical shaft *t*, Fig. 7385. The tension of the belt *u* that drives the main cutter-spindles *e* is regulated by the pulley *v* carried on the lever *w*, which allows the spindle *e e* to be adjusted without changing the stress upon the belt. In case of the belt *u* breaking, a spring *x* is provided to stop the weight *y*. Power is communicated to the machine, when from above, to the pulley *z*, or when from below, to the fast and loose pulleys at A.

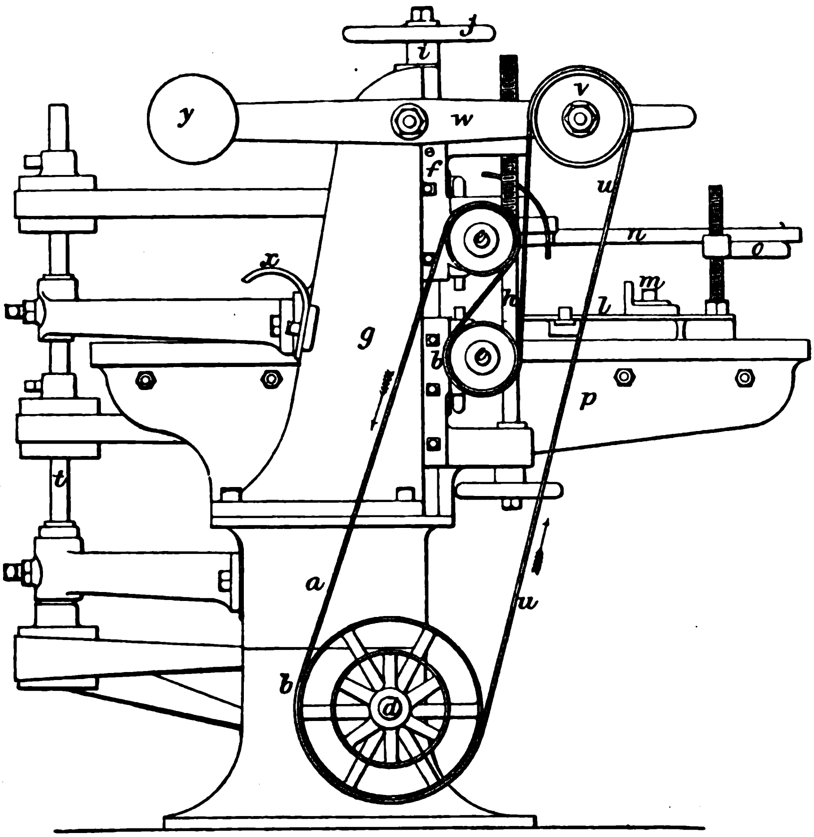
Boring, after tenoning and mortising, is next in importance among the regular operations in wood framing. Boring machines for regular purposes consist in vertical and horizontal machines, as they are termed.

Figs. 7388, 7389, are of a vertical machine arranged with two spindles that have a lateral adjustment of 10 in., and a vertical range of 18 in. *a* is the main frame or supporting standard on which all the parts are mounted; *b* is a strong bracket bolted on the front to support the sliding carriage *c*; this bracket *b* is pivoted, and can be set to various angles on the front of the column *a*, so that the timber *d* can be bored at various angles; *e*, *e*, are boring spindles carried in bearings formed in the brackets *i*, *i*, and driven by the bevel-wheels *m*, pulleys *n*, *n*, and shafts *o*. The brackets *i*, *i*, are moved out or in upon the frame *r* by means of racks and pinions operated by the wheels *s*, *s*. The spindles *e*, *e*, and augers *f*, *f*, are fed down into the wood *d* by means of the levers *t*, *t*, and the handles *u*, *u*, and are lifted and kept at the top of their stroke when not in use by means of the weights *v*, *v*. The shafts *o* move loosely through the pulleys *n*, *n*, and the bearings *z*, to allow of the lateral adjustment of the spindles *e*, *e*, and brackets *i*, *i*. The table or carriage *c* is moved by the hand-wheel *g* and a rack and pinion. The wood is clamped by the sliding jaw *h*.

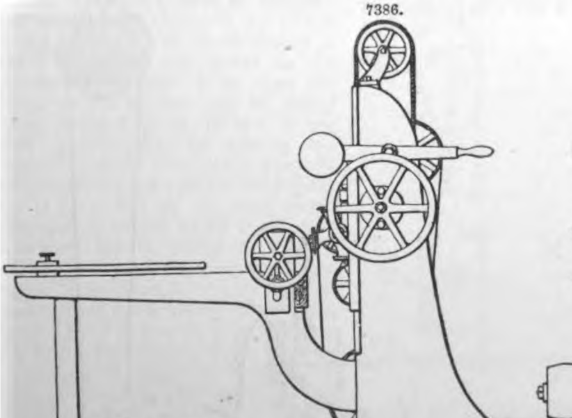
Figs. 7390, 7391, are elevations of a horizontal boring machine with a single spindle. *a* is the main standard to support the spindle, *b* a stand to support the lumber, and *c*, *c*, auxiliary stands to support the ends of long pieces. The spindle *d* runs in bearings attached to the movable frame *e*, which slides up or down on the stand *a*, and is operated by the hand-wheel *f* and a rack and pinion

at *g*. The frame or saddle *e* is counterweighted by the weight *h* and a wire rope *i*, passing over the pulley *k*. Motion is given to the spindle *d* by the belt *l l* from the countershaft *m*, the swinging

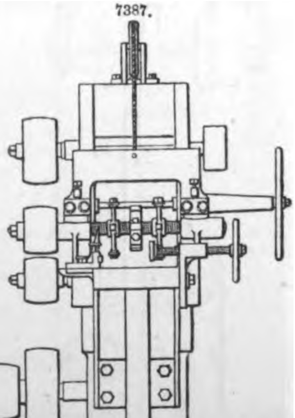
7385.



7386.



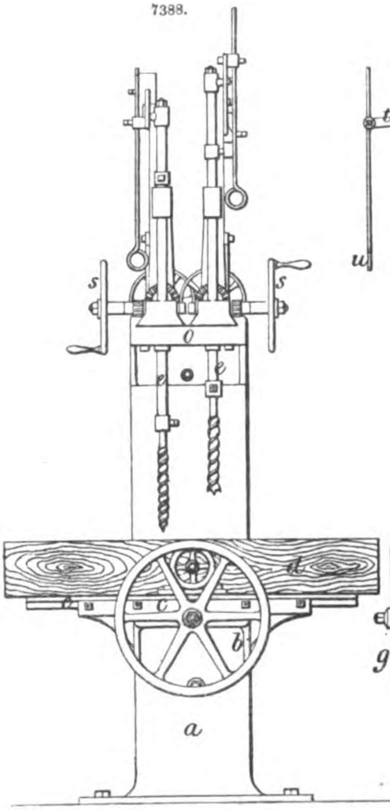
7387.



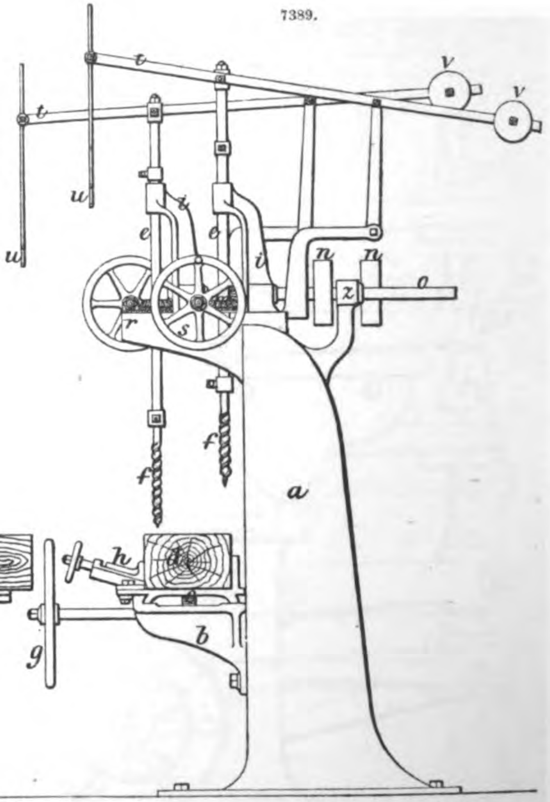
frame *n* and weight *o* compensating for the movement of the spindle *d*, and keeping the tension of the belt *l* uniform. The spindle *d* is moved forward by the handle *r*, which is attached to a sliding rod *s* set parallel to the spindle *d*. All the parts are mounted on the sole-plate *t*, which forms a base for the machine. The main column *a* and the boring spindle with its attachments are often furnished and operated with the machine, Figs. 7378, 7379, in addition to the mortising attachment, so that the boring and mortising may be done at the same time, or either separately, the same carriage answering in both cases. For work of the heavier class the lateral adjustment of the spindles in

horizontal boring machines is necessary, because of the great inconvenience, and sometimes the impossibility, of moving the lumber instead of the auger.

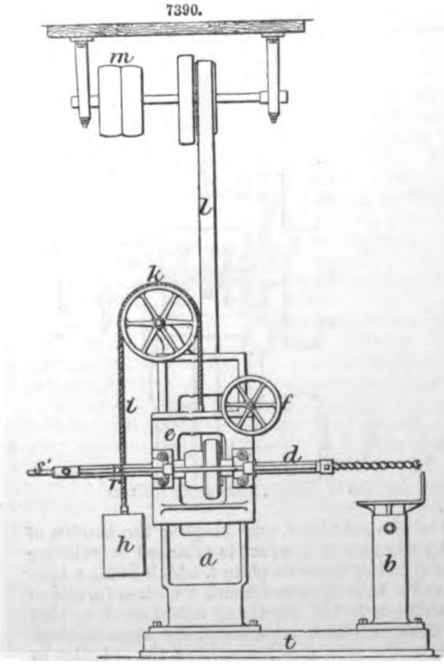
7388.



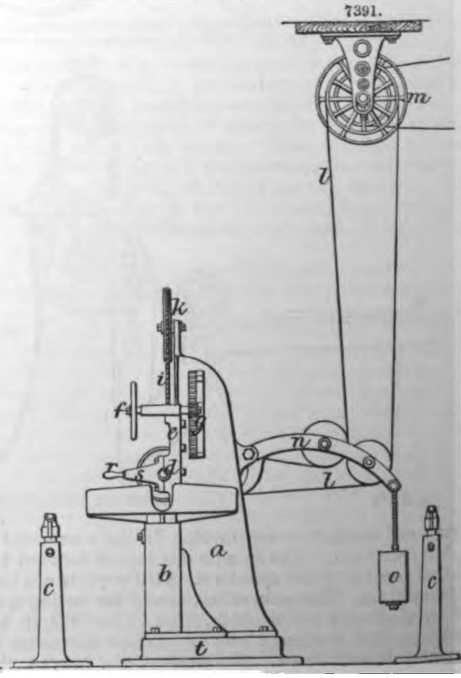
7389.



7390.



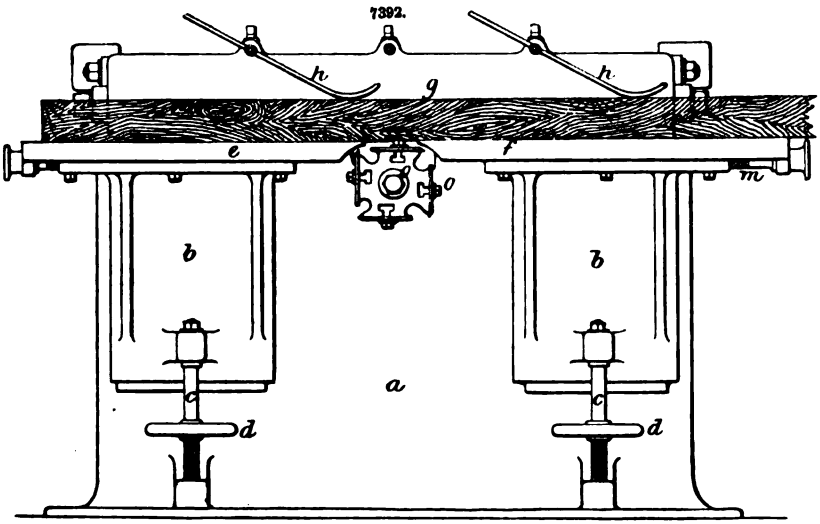
7391.



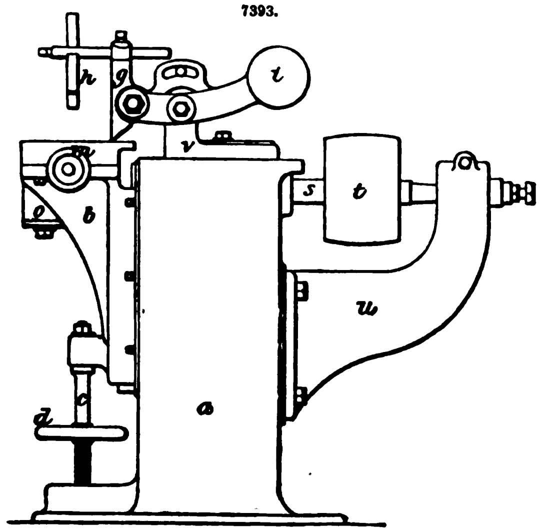
Regular shaping comprehends a variety of operations that might be termed planing, sawing, moulding, and so on; but the term is used to convey an idea of special as distinguished from general operations, where there is not a duplication of pieces nor a large number prepared. Irregular shaping applies to the preparation of pieces that have irregular outlines, pieces that cannot be moulded or planed in straight lines or in true circles. The lumber in irregular shaping, as it can neither be revolved about a fixed centre nor moved in straight lines, has to be formed by patterns with an outline corresponding to the shape of the finished piece required.

Referring first to machines for regular shaping, they consist mainly of hand-feeding machines; the irregular character of the work not justifying or requiring the complication that would be unavoidable in presenting and adjusting the material automatically. Figs. 7392, 7393, are of a

7392.



7393.



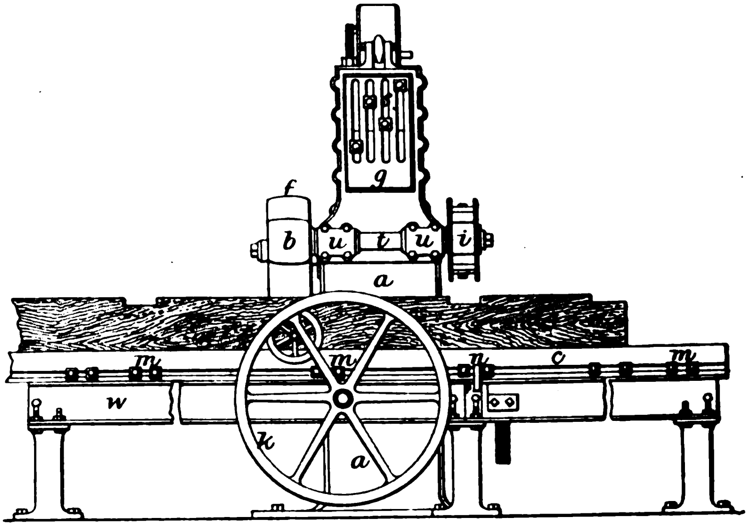
shaping machine that has a great range of adaptation for moulding, grooving, rebating, bevelling, and shaping; *a* is the main frame, cast in one piece; *s* is the cutter-spindle, and *o* the cutter-block; *t* the driving pulley; *e* and *f* are tables on which the wood *y* is moved. Tables *e*, *f*, have an independent adjustment vertically by means of the screws *c* and hand-wheels *a*, also a horizontal adjustment on the top of the brackets *b*, so that the throat at the cutters may be closed up or widened, as the nature of the work may require, by turning the screws *m* and *n*. The gauge *g* can be set at various angles for bevelled work, and is supported on the main frame independent of the tables *e* and *f*, so that they can be raised or lowered without changing the position of the gauge. The bracket *b* is moved forward or back upon the top of the main frame *a* so as to receive pieces of any size within the capacity of the cutters; or in case of transverse cutting for gains or notches, the guard *g* and bracket *b* may be removed, to leave the top of the machine entirely clear. *u* is a strong bracket bolted to the main frame to support the spindle *s*.

Figs. 7394, 7395, are of a cutting and shaping machine, intended mainly for cutting transversely gains, notches, or shaping the ends of framing for railway-carriage work, to which the machine is especially adapted.

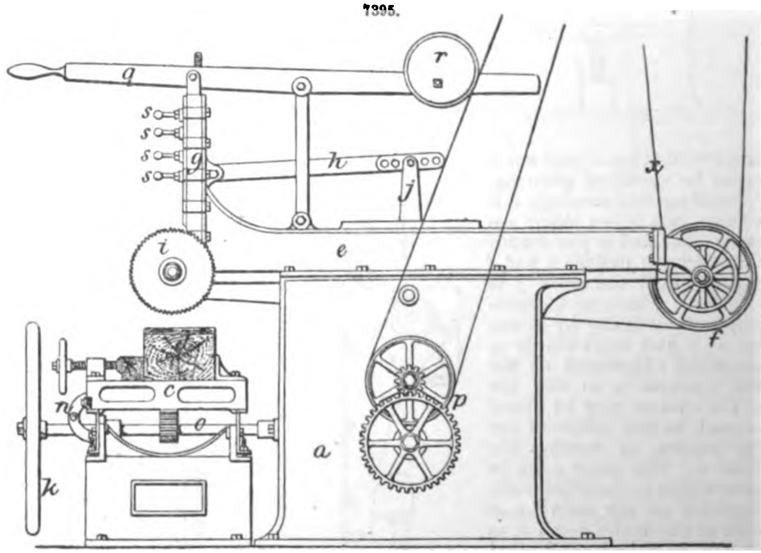
Its functions and movements conform somewhat to those of a metal-shaping machine, except in respect to the cutters. *a* is a cored box frame that supports the cutting mechanism, consisting of the cutters *i*, spindle *t*, and the reciprocating cutter-bar *e*; *w*, *w*, are wrought-iron rails, upon which the carriage *c* is moved by the pinion at *o* and the large hand-wheel *k*; *d* is the lumber to be cut, which is placed upon the table C, either parallel or at an angle, as may be required, and held by

wedges or screw-clamps. The carriage *c* is provided on its front edge with a series of stops *m*, *m*, *m*, that come in contact with the hinged dog *n* and determine both the length and position of the

7394.



7395.

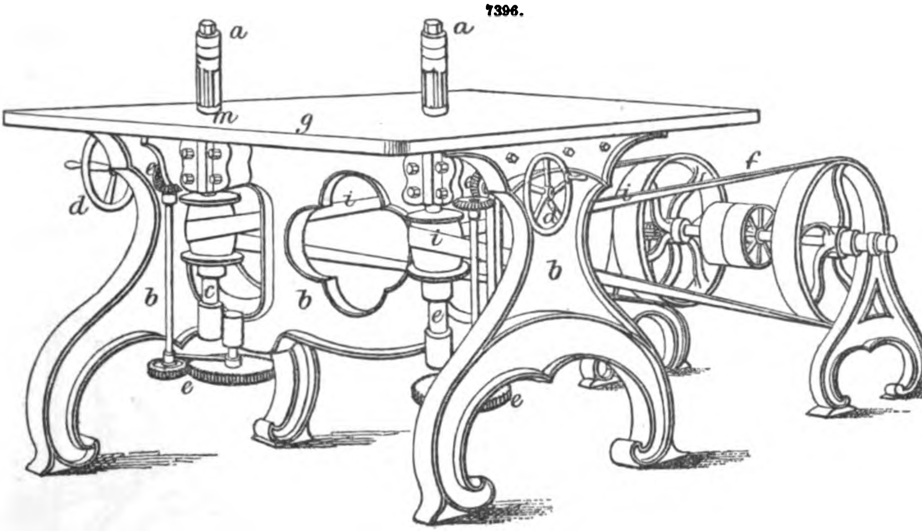


notches or gains that are to be cut on each piece. The bar *e* has a reciprocating movement of eight strokes a minute given to it by the gearing at *p*, the lever *j*, and link *h*. A crank on the inside of the frame working into a slot in the lever *j* gives a slow forward and a quick movement back stroke to the bar *e*; this arrangement also provides for a more uniform rate of movement in the forward stroke than would be attained with a positive crank and link connection.

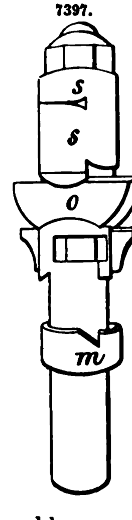
The traversing movement of the cutters and saws at *i* is variable by adjustment from 0 to 20 in. The cutter-spindle *t* is inserted in the bearings *u* cast upon the sliding saddle *g*; this saddle is balanced by the weight *r*, and is moved up or down at will by the operator, who keeps his hand upon the handle at the end. The reciprocating movement of the bar *e* is slow enough; thus there is time in the intervals at the change of the stroke to raise the saddle *g* and cutter-spindle *t* on the back stroke and depress them again, so that the cutters *i* are brought in contact with the wood on the forward stroke. The depth of the cut is regulated by a system of adjustable stops at *s*, *s*, *s'*, *s'*, which are operated at will, and give four independent adjustments to the saddle *g* or the cutters *i*. The cutter-spindle *t* is driven from the shaft at *f*, also carried on the reciprocating bar *e*, and is bolted from above to preserve a uniform tension of the driving belt *x*; *s* is the belt to drive the reciprocating gearing at *p*. This machine has been applied to the manufacture of hatch gratings and other purposes in dockyards.

Fig. 7396 is a perspective elevation of an irregular shaping machine with right and left spindles, for moulding forms from patterns. Fig. 7397 is an enlarged view of the cutters and clamping

7396.



7397.



collars. *b b b* is the frame that supports the two spindles *a*, *a*, and the top or table *g*; the spindles *a*, *a*, have a rotary motion in opposite directions given by the angular belts *i* connecting them with the countershaft *f*. The spindles *a*, *a*, are raised or lowered independently by means of the gearing *e* and hand-wheels *d*. The two spindles require an accurate adjustment vertically, so that the cutters will produce the same form in changing from one spindle to the other to suit the grain of the wood. The two spindles are required so that by changing the work from one to the other the cutting may be done with the grain, and thereby guard against accidents. The cutters, which have to be in duplicate pairs right and left hand, are held between the ring-collars, Fig. 7397. These collars *s'*, *s'*, have triangular notches or grooves that embrace the ends of the cutters, which are bevelled off to fit as at *o*.. By using a number of these collars *s*, of proper width, various combinations of cutters may be formed so as to produce mouldings of different kinds.

The wood is mounted on and fastened to a model that has the same outline as the piece wanted, except that the edges are square, and rest against the running collars at *m*. By pressing the pattern or form against the spindle and moving it along at the same time, the wood is acted upon and shaped by the cutters *o*.

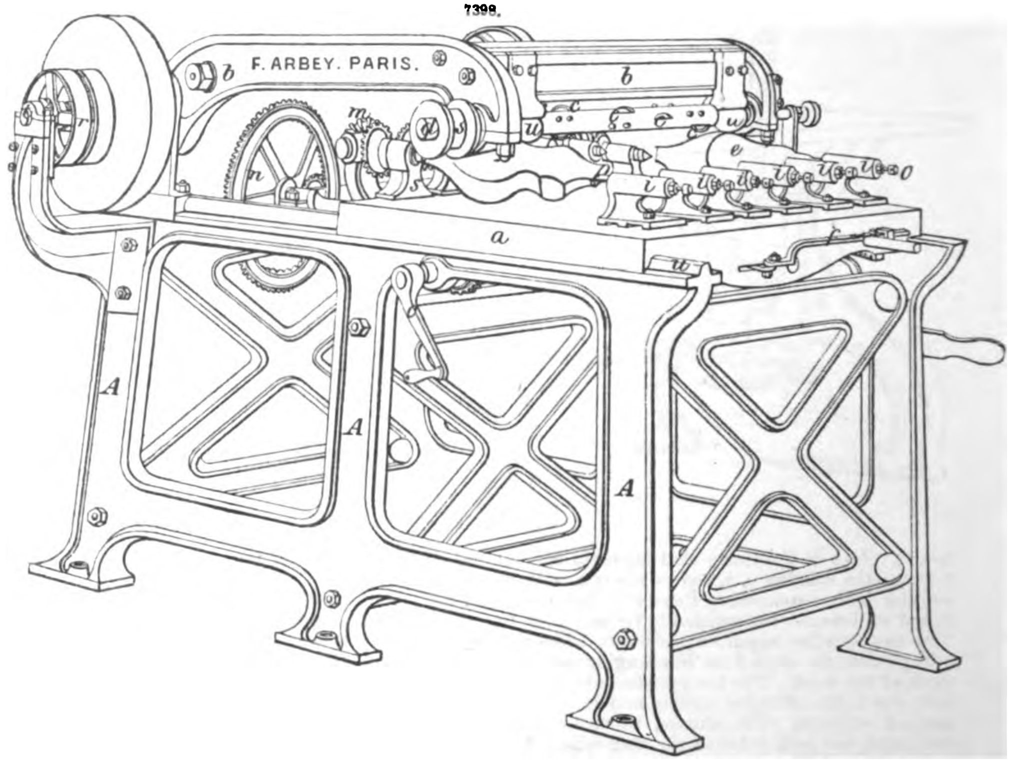
Fig. 7398 is an irregular shaping machine with automatic action, by Fd. Arbey, of Paris, adapted to the manufacture of gun-stocks, handles for tools, wheel-spokes, shoe-lasts, and so on. A is the framing, bolted together in the usual manner; *a* is a strong sliding carriage moving on planed guides *u*, by means of feeding mechanism on its under side driven by the gearing at *n*; *b* is a swinging frame pivoted at the centre *t*, and provided with bearings for the cutter-spindle *d*; *i*, *i*, *i*, *i*, are supports for the blanks to be shaped, and the two stands *o*, *o*, for the patterns or forms. These stands, *i* and *o*, correspond to the poppet-heads of an ordinary lathe, and have counterparts or head-stocks *s*, at the opposite end of the carriage *a*, which are provided with revolving or driving spindles driven by bevel-wheels *m*.

The blanks being placed between these points are with the patterns *e* all revolved in unison by the gearing at *m*. At *u u*, surrounding the cutter-spindle, are spherical bearings that have the same curvature as the cutters *c*, *c*, *c*, *c*, and rest on the two patterns *e*, *e*. By rotating the patterns *e*, *e*, an oscillating motion is given to the frame *b*, conforming to the changes of the pattern *e* as it progresses with the carriage *a*, and the cutters *c*, *c*, *c*, *c*, cut four duplicates from the blanks that have been placed between the patterns *e*, *e*, on the stocks *i*, *i*, *i*, *i*. The feed-motion of the carriage *a* is arrested by the mechanism seen at *f*. The cutter-spindle *d* receives motion from the pulleys *r*.

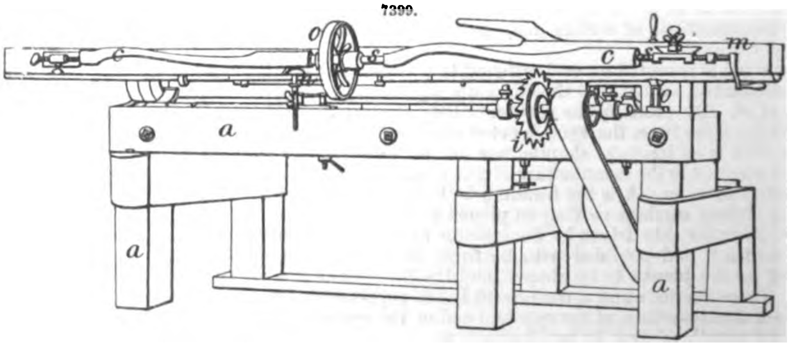
Fig. 7399 is another automatic-acting machine for shaping irregular forms arranged to act upon one blank at a time, but capable of producing more intricate forms, especially tool-handles that are long, and too flexible to be acted upon with the ordinary cutters; *a* is the framing, in this case of wood, which is for some reasons preferable; *i* are the cutters that act upon the handle *c*; *e* is the pattern, *o* is a pulley mounted on a short shaft provided at each end with spur centres that give a coincident rotation to the piece *c* and the pattern *e*; the pattern *e* resting on *a*, the convex support at *n* causes a vibrating or rocking motion of the main carriage *m*, on which is mounted the supports for the handle and pattern. This carriage *m* has a longitudinal feed-motion imparted to it by a screw or a chain placed behind it, and not seen in the engraving. The rotation of the piece *c* and the end movement combined causes the saw *i* to cut away a narrow section of wood in a spiral line, the cutters acting so rapidly, and the intervals between cutting being short,

the strain upon the piece *c* is so inconsiderable that even the thinnest handles can be formed from large or crooked pieces. These machines are extensively used in North America for manufacturing

7398.



7399.



axe, hammer, and pick handles, the product a day being about 300 pieces to each machine, two of which one man can attend.

Dovetailing Machines.—It is difficult to account for the many and persistent experiments that have for sixty years past been made in endeavouring to produce dovetailing machines. There is certainly much less economy of labour to be expected from a successful dovetailing machine than almost any other directed to wood conversion; and the many inventions of machines of this kind have been called out rather from a spirit of ingenuity than from any considered advantage to be gained by them.

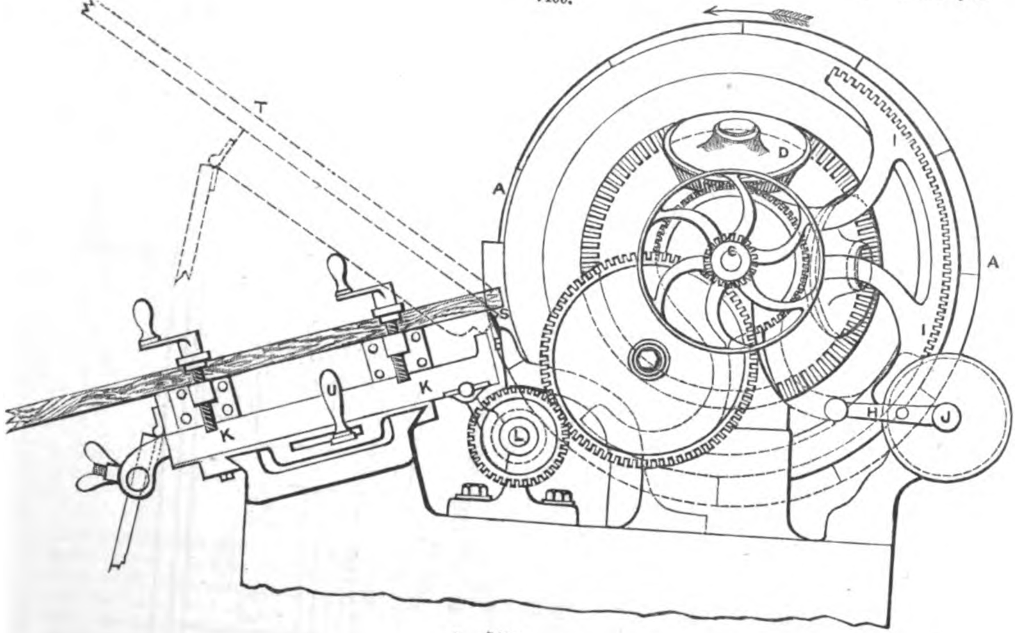
In dovetailing furniture drawers, which comprises the greater share of the dovetailing that is to be performed, there is but little need of dovetailing machines. No other operation connected with the manufacture of such drawers can be so rapidly and so perfectly done by hand as the dovetailing.

It is one of those peculiar operations where but little power and but a limited amount of edge can be applied, and the adjustment or changes are so numerous and rapid that judgment is continually necessary in directing the tools, while the strength of the operator is not only sufficient for the work, but is equal to the amount of power that can be applied by machines.

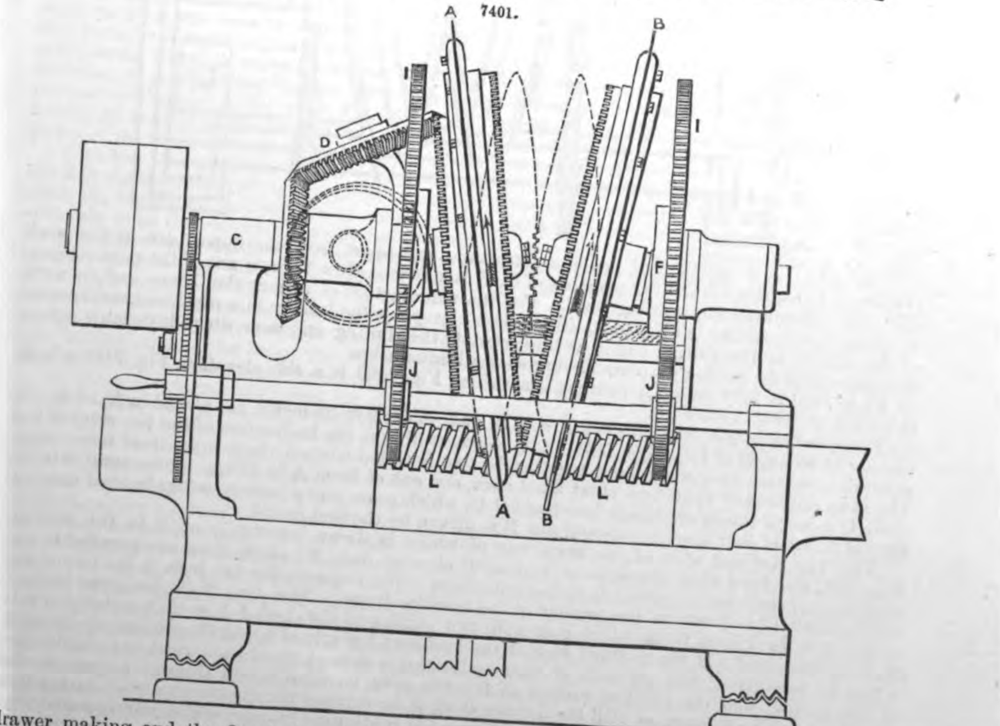
Sir Samuel Bentham eighty years ago invented the conical cutter dovetailing machine, and

describes it in 1793. Nearly all machines since invented have been modifications of his principle, Armstrong's forming the most notable exception, and the result, taking the history of the whole art since Bentham's time, may be summed up in the statement that while dovetailing machines have effected a considerable saving of labour in certain kinds of work, such as making plain rectangular boxes, packing cases, and other work where the joins and holes are pervious; yet

7400.



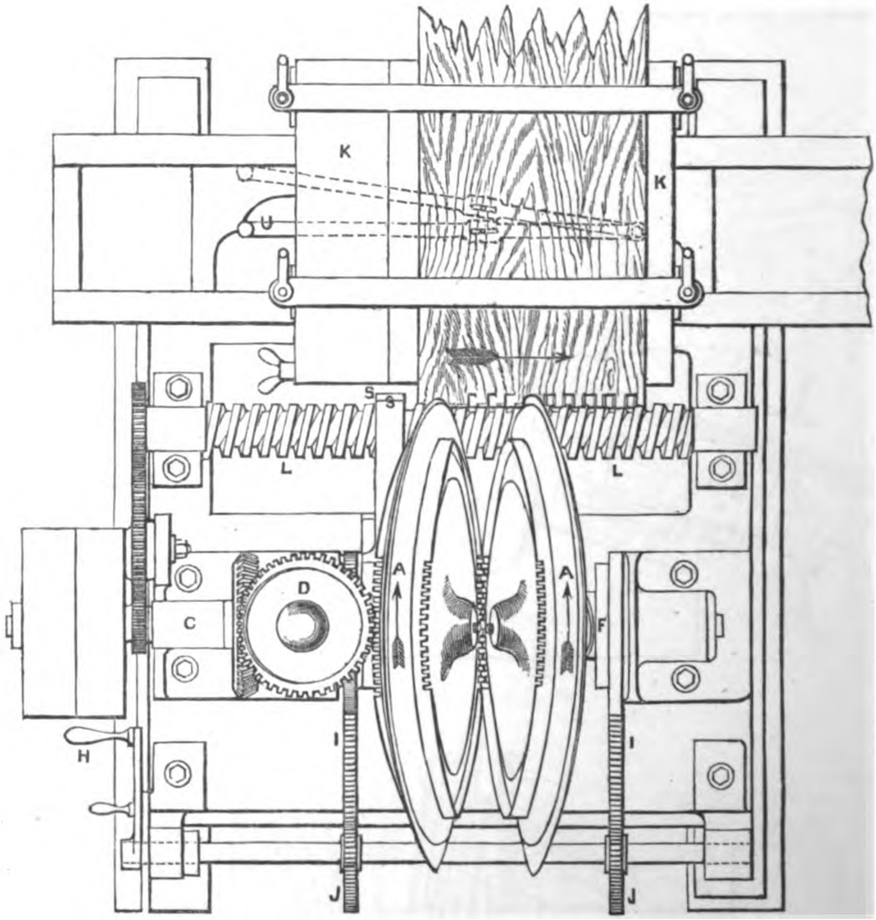
7401.



drawer making and the finest classes of dovetailing are done as cheaply and as well by hand as by machines. This statement is not so much based upon the assumed conditions of the work, nor

the nature of the machines, as upon the fact that but few wood manufacturers use dovetail machines except for rough work that admits of a great range of duplication.

7402.



Considered as a machine of novel construction, and apart from the importance of the work performed by it, the dovetailing machine of S. T. Armstrong, New York, is one of the most remarkable ever introduced for working wood. For the manufacture of rectangular boxes and for work where open dovetailing is allowable, this machine prepares the lumber in a rapid manner, because of the number of the cutting edges, as these obviate the dulling and wear which invariably occurs with machines for similar purposes having only a limited edge.

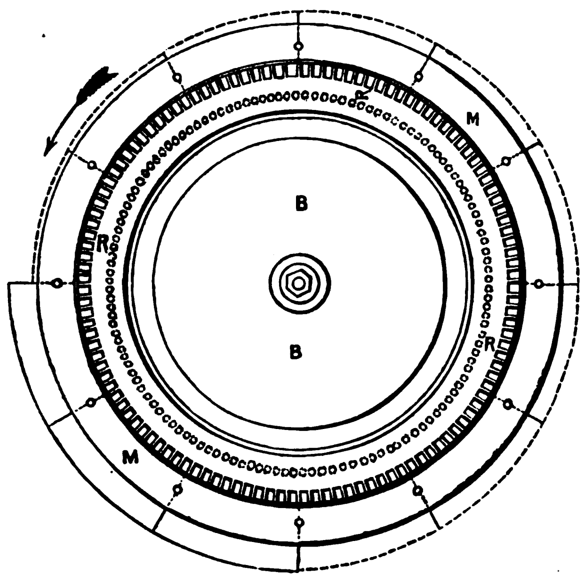
Figs. 7400 to 7404 are of Armstrong's machine; Fig. 7400 is a side elevation, Fig. 7401 a back elevation, and Fig. 7402 a plan.

The two compound circular saws A and B, each about 2 ft. diameter, are placed inclined to one another at an angle of 18°, Figs. 7401, 7402, corresponding to the inclination of the two sides of the dovetail pins, and they are geared together by two bevelled-toothed rings upon their inner faces. The saws run loosely upon two short fixed axes, and one of them A is driven by the main driving shaft C through the intermediate bevel-wheel D, which gears into a corresponding toothed ring on the outer face of that saw; the second saw B is driven by the first one A.

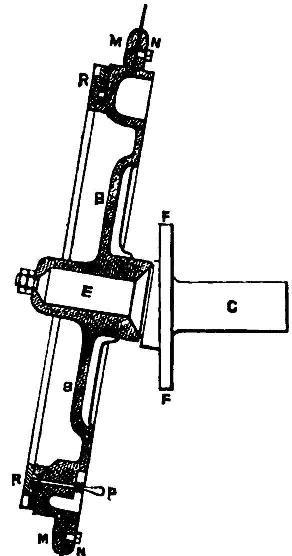
The two inclined axes of the saws, one of which is shown separately at E in the section, Fig. 7404, are fixed upon the faces of two small circular discs F; these discs are parallel to one another, and each has a spindle G on the outer face. The two spindles are both in the line of the driving shaft C, and turn in two sockets in the machine frame. The discs F, F, have two toothed sectors I, I, fixed upon them, which gear with two pinions on the shaft J J, so that on turning this shaft by the handle H the inclined axes of the two saws are turned round simultaneously through a quarter revolution; the direction of their inclination is thus changed from vertical to horizontal or the reverse, and the point of contact of the two saws is rolled round through a quarter of a revolution. The connection with the driving shaft C for driving the saws is preserved during this change of position by the intermediate bevel-wheel D continuing in gear, whilst rolling round into the position shown by the dotted lines in Figs. 7400, 7401, the wheel D being carried upon the arm of one of the toothed sectors I. The object of this movement is to change the action of the saws

from cutting the pins to cutting the holes of the dovetails. The wood to be cut is clamped down upon the table K, Figs. 7400, 7402, which is placed radially to the saws, so that the cuts are at right

7403.



7404.



angles to the face of the wood, and when the dovetail holes are to be cut, the two saws are required to be at their full inclination to each other in plan, but parallel on the edge of the wood, as in Figs. 7407, 7408, so that one saw cuts the right-hand side and the other the left-hand side of each dovetail hole; and the two oblique axes of the saws are made for this purpose at the inclination to give the angle of 18° between the two saw faces. But when a rotation of a quarter of a circle is given to these two axes by means of the toothed sectors I, I, the direction of their inclinations is then brought at right angles to the face of the wood to be cut, as in Figs. 7405, 7406, and the edges of the saws, where in contact with the wood, are parallel to one another in plan but inclined in elevation, so as to cut the dovetail pins with parallel sides on the face of the wood, Fig. 7405, but inclined on the edge of the wood, Fig. 7406. By this means the pins and holes of the dovetails are formed at exactly the same inclination, by the simple expedient of cutting them at two different points of the circumference of the saws, at right angles to each other.

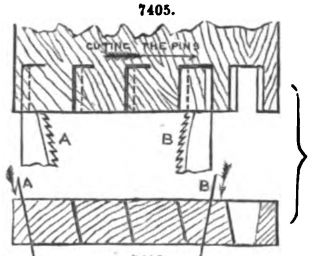
Each saw cuts one half of a pin or hole in a single revolution. The saw-blade is made plain for the first three-quarters of its circumference, like an ordinary circular saw, but with a spiral outline gradually increasing in diameter, as shown in Fig. 7403, so as to increase the depth of cut continuously until the bottom of the dovetail is reached. The last quarter circumference of the saw-blade is made truly circular, but has the cutting edge bent over at right angles, so as to cut at the side, for cross cutting the bottom of the dovetail; and the lateral projection of the flanged blade gradually increases until it is equal to half the width of the bottom of the hole. For cutting the pins of the dovetail, the two saws being then parallel in plan, Fig. 7405, the flanged saw-blades have the edge bent over inwards exactly at right angles, for cross cutting the bottom of the dovetail; but for cutting the holes, the flanged blades are bent over outwards to an angle of 81° as in Fig. 7407, the two saws being then inclined at 18° towards each other in plan.

In order to traverse the wood for obtaining a succession of cuts, the table K on which it is clamped is traversed across in front of the saws with a continuous feed-motion by means of the bed-screw L, driven by spur-gear from the main shaft C; and the blade of each saw, instead of being at right angles to the axis upon which the saw revolves, is set inclined like a screw-thread, with 1-in. pitch, that being the intended pitch of the dovetails. The bed-screw L also traverses the wood 1 in. forwards in each revolution of the saws; and the saws and the wood are consequently made to traverse exactly together, each saw following up its own cut correctly, until the cut is completed at the end of one revolution of the saw; and the saw then commences the next cut at the pitch of 1 in. The second saw B does not commence cutting until the first saw A has advanced a certain distance in the work, as in Figs. 7405 to 7412; and it continues cutting throughout at the same distance behind the first saw, but completes all the pins or holes at the end.

The saw-blades are made in short segments, each 6 in. long, Fig. 7403, and are fixed in their places by fitting into a turned recess M M in the circumference of the cast-iron boss B; they are held in their places by a series of segment plates N, N, at the back, tightened up by two bolts each. The saw segments are readily released and changed, when it is required to set the machine for a different size of dovetail, or to change from cutting the pins to cutting the holes; and five different sets of blades are kept for this purpose, to give the extent of range in dimensions of dovetails that is required with each machine; the several sets vary proportionately both in the plain and the flanged portions of the blade.

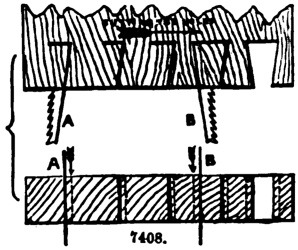
In changing the machine from cutting the holes to cutting the pins of the dovetails, the two saw-blades require a slight adjustment endways relatively to each other, in order to take up the

7405.



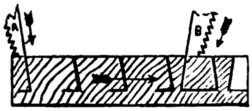
7406.

7407.

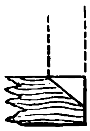


7408.

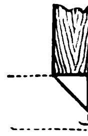
7409.



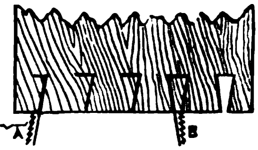
7410.



7411.



7412.



slack that would be caused in the fit of the dovetails by the thickness of the saw-cuts themselves, and to make the pins fit true and tight in the holes without any shake. This adjustment is obtained by rotating the second saw B a certain distance round upon its axis E, Fig. 7404, the toothed driving ring R R being for this purpose made loose upon the boss B of the saw, and locked to it by the pin P for driving the saw. As the circumference of the saw-blade is itself in the form of a screw-thread of 1-in. pitch, the effect of turning the saw round upon its axis E is to shift endways the point of commencing the cut; and by this means therefore the cut of the second saw is made to follow that of the first at the required distance. The ring R R is marked with graduations corresponding to the several adjustments required for changing the machine from one size of dovetail to another, or from cutting the pins to cutting the holes of the dovetails; and the adjustment includes the required allowance for clearance, to make the pins and holes fit together with any degree of tightness that is desired, without requiring any dressing by hand.

The saw segments are all made exact duplicates of one another in the portions fitting on the boss of the saws; and consequently in the wear of the saws, as the segments become gradually reduced in diameter by the sharpening, they are simply shifted each to the adjoining place in the circumference of the saws, a new segment being required only for replacing the last or largest flanged segment. The change also from the flanged to the plain segments is made by filing down plain teeth in the first flanged segment when worn out.

The table K carrying the wood is made with a hinge movement, so that it can be inclined at an angle of 45° to its usual radial position, as shown by the dotted lines at T.

The table K is mounted upon two slides at right angles to each other, like the slide-rest of a lathe; the lower slide receives the traverse feed-motion from the bed-screw h, and the upper slide is moved inwards towards the saws by the hand-lever U, through a distance equal to the depth of the dovetails. The upper slide also carries a half-nut, which gears with the traverse screw L; so that when the wood is advanced up to the saws by the hand-lever U, the nut is at the same time thrown into gear with the screw L, causing the traverse feed-motion of the wood to commence.

A scriber S is used to mark off on the under side of the wood the bottom line of the dovetail pins and holes, in advance of the saws, to prevent the edge of the wood from being broken on the under side. This scriber serves also as a gauge for setting the edge of the wood to be cut, which is first clamped down upon the table K with its edge level with the scriber S, and the wood being then moved inwards towards the saws by the hand-lever U, this gives the correct depth of cut for the dovetails.

The working speed of the machine is 150 revolutions a minute, one pin or hole of the dovetail being cut at each revolution.

Evart's Dovetailing Machine.—The machine, Fig. 7413, is one of the most complete of those operating with conical cutters capable of dovetailing at various angles, and can be used to advantage in ship joinery or elsewhere when drawers or boxes are made of other than a rectangular form.

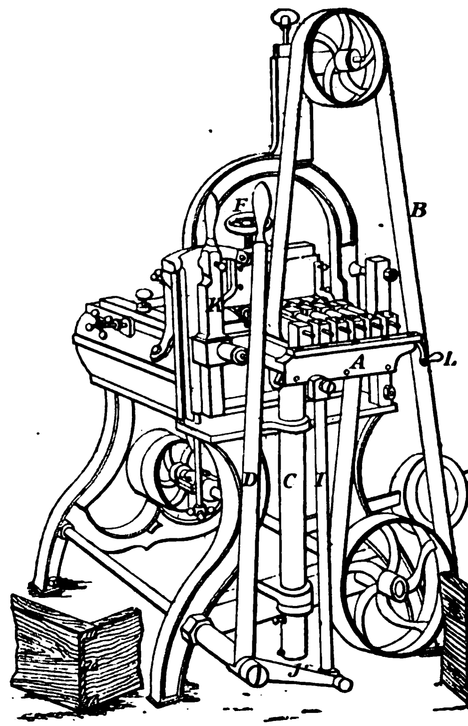
A is the spindle-frame in which is mounted six or more cutting spindles all driven by the belt B. This frame is supported on the cylindrical slide-bar C, that allows the cutters and spindles to be raised or lowered by means of the hand-lever D and the link I.

The carriage A moves horizontally on slides, and is guided in this direction by the bar K. When this bar K is set in a line coincident with the sliding support C, the spindle-frame and cutters rise and fall vertically; but when the guide-bar K is set at an angle it gives a compound motion to the spindle-frame A in rising and falling, and the cutters pass through the wood, which is placed on the platform at the rear of the machine, at an angle to correspond with that of the guide K. The various angles and movements being graduated by figured scales, render the adjustment simple and sure.

The table on which the wood is placed and the clumps operated by the wheel F have also various adjustments that give a large range of functions to the machine.

Automatic Turning Machines.—This class of machinery has received a great deal of attention in the United States of America, where wood turning is extensively carried on.

7413.

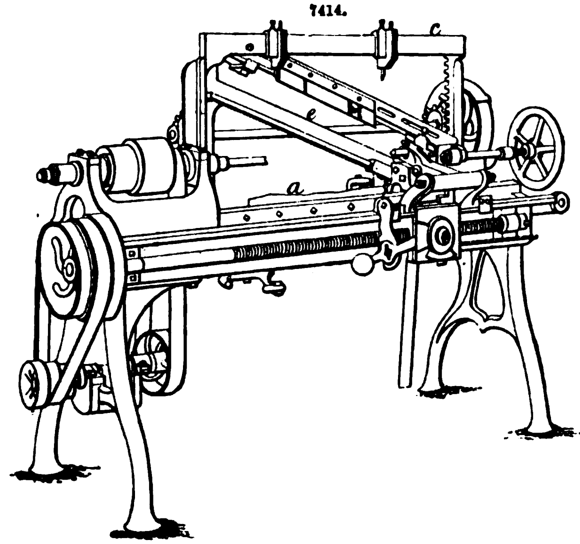


Hand turning is not only expensive as a wood-converting process, but is also very imperfect so far as the attainment of accurate or uniform sizes and configuration is concerned, and there has been no want of incentive for the development of machine turning.

It was for a long time regarded as impracticable to produce smooth work by machine processes; the configuration and accuracy were easily attained, as well as the expected gain in the speed of the operations, but the smooth surface that is left by hand chisels seemed to be unattainable by the machines. Ingenuity and perseverance, however, finally triumphed over this obstacle, and machine turning is now performed quite as smooth as hand turning. The machine shown at Fig. 7414 is a modification of one of the American automatic lathes. There are others that operate upon analogous principles, but the one selected will convey a correct idea of their operation.

The lathe in all of its parts corresponds to an engine lathe for metal turning, having a slide-rest and screw-feed, with planed guides and a sliding tail-stock. The wood is placed between the centres, and is first acted upon by cutters, that reduces it to a cylindrical form, and to fit a die or ring-rest attached to the sliding carriage; behind this rest there follow two or more hinged tools that are raised and lowered by means of the pattern *a*, on which they slide giving form to the piece, but leaving it rough. As the carriage moves along, the frame *c* moves down at the same time, bringing the cutter *e* in contact with the piece. This cutter *e* is shaped on its face so that the edge follows the profile of the piece and takes off a thin shaving in the same manner as is done with a hand chisel, leaving the surface smooth. The frame *c* rises and falls automatically; in fact, all the movements except placing the wood and starting the wood, are automatic. The cutters are shaped by automatic machinery in their manufacture, and their expense is so reduced as to form no obstacle to their use.

7414.



See Machine Tools.

WORM. Fr., *Filet d'une vis;* Ger., *Gewinde;* Ital., *Vite perpetua;* Span., *Tornillo sin fin.*

The thread of a screw is called the worm. The name is also given to a short revolving screw, the threads of which drive a wheel by gearing into its teeth or cogs; *a worm-wheel.*

WRENCH. Fr., *Tourne à gauche;* Ger., *Windeisen;* Ital., *Chiave da dadi;* Span., *Destornillador.* See Hand-Tools.

ZERO. Fr., *Zéro;* Ger., *Null;* Ital., *Zero;* Span., *Zero.*

Zero is the point from which the graduation of a scale, as of a thermometer, commences. Zero

in the thermometers of Celcius and Réaumur is at the point at which water congeals. The zero of Fahrenheit's is fixed at the point at which the mercury stands when immersed in a mixture of snow and common salt. In Wedgewood's pyrometer the zero corresponds with 1077° on Fahrenheit's scale.

ZIGZAG. Fr., *Zigzag;* Ger., *Zickzack.*

See Fortification.

ZINC. Fr., *Zinc;* Ger., *Zink;* Ital., *Zinco;* Span., *Zinc.*

The name zinc is derived from the German zinn, tin, with which metal zinc was for a long time confounded. Commercially, it is known as spelter. Zinc is a bluish-white metal, very lustrous externally, and when broken exhibits a foliaceous crystalline texture. At ordinary temperatures it is somewhat brittle, but when heated above 212°, it becomes perfectly ductile and malleable, and may then be beaten out into thin sheets, or drawn out into wire. At a temperature of 400° it becomes so exceedingly brittle that it may be easily pulverized. At 773° it fuses, and above that temperature it is volatilized, and may be distilled. If the vapour be exposed to the air, it burns very brilliantly with a bluish-yellow flame, and is converted into oxide of zinc, which is deposited in copious white flakes, the flowers of zinc, or *lana philosophica* of the older chemists. In this state of oxide, it is largely prepared as a pigment, and is known as zinc white. It is of a purer colour than white-lead, and, unlike the latter, it does not tarnish and blacken with sulphuretted hydrogen; it is also much healthier for use by operative painters, but unfortunately in this respect, its use is limited by a want of body. The discovery, towards the beginning of the present century, that zinc could be rendered malleable and ductile has greatly extended its uses, and placed it in a position of considerable importance with respect to the other metals. One property possessed by zinc is that of becoming coated, when exposed to a moist atmosphere, with a thin compact film of oxide, which effectually protects the metal beneath from further oxidation. Hence the value of zinc as a material for roofing, and also for protecting the surface of iron from oxidation.

The symbol of zinc is Ƶn; its atomic weight, 32·75; molecular weight, 32·75; specific gravity, 6·8.

Zinc is found in nature only in a state of combination; its principal ores are the sulphuret known as blende, and the silicate and carbonate which are confounded under the name of calamine. Blende, called in Cornwall black-jack, contains when pure about 67 per cent. of zinc; it is, however, seldom found in a pure state. The usual composition of English blende is zinc 61, iron 4, and sulphur 35. It occurs in all the older geological formations, and is frequently found associated with the ores of copper and tin, but chiefly with the ores of lead. In this country the localities which produce blende are Wales, the Isle of Man, Derbyshire, and Cornwall. Sweden is very rich in this mineral, and in several localities on the Continent it is found in considerable quantities. Blende is of a brownish colour; but in this country, in consequence of the presence of sulphuret of iron, it has a dark appearance; hence its name of black-jack. It crystallizes in the form of the rhomboidal dodecahedron, and the crystals possess considerable brilliancy. Calamine, when pure, contains about 52 per cent. of zinc; but its composition varies much. It is usually of a dull yellow or of a reddish-brown colour; its primitive crystalline form is the rhombohedron, but, like blende, it occurs more frequently massive than in crystals. Formerly large quantities of this mineral were raised in Somersetshire and exported as ballast, its value being then unknown; Cumberland is the only locality in this country that now produces calamine in considerable quantities. Belgium, Silesia and Carinthia, and the north coast of Spain, are rich in this ore.

Zinc is extracted from its ores by calcining them with carbon, after having roasted them and reduced them to a fine powder in clay pipes arranged in furnaces constructed for that purpose. The blende is converted into oxide by oxidation, and the carbonate also gives oxide by losing carbonic anhydride. The oxide when calcined with carbon gives metallic zinc. The apparatus employed in the reduction of zinc may be constructed to allow the metal to flow out at the bottom as it fuses; this method is known as distillation *per descensum*, and is the one usually employed in England. With another arrangement of the apparatus, the zinc is reduced to vapour and then distilled; this latter method is known as distillation *per ascensum*.

The zinc of commerce is never perfectly pure; it always contains a little carbon, arsenic, iron, manganese, and more rarely, tin, copper, lead, cadmium, and sulphur. It cannot be freed from these metals by distillation even. The best way to obtain it pure is to reduce pure oxide of zinc by equally pure carbon, prepared by calcining loaf-sugar. Zinc decomposes vapour of water at 212°; when cold, it substitutes itself for the hydrogen of the acids; the preparation of hydrogen is founded upon this property. Gold, silver, platinum, copper, bismuth, antimony, tin, cadmium, mercury, lead, and the other metals less oxidizable than itself, are precipitated by zinc from their saline solutions. When hot, the hydrates of potassium and sodium, and even the solution of ammonia, dissolve zinc with a liberation of hydrogen. With the fixed alkalies, there is formed in this case alkaline zincates.

$$\underset{\text{Potassa.}}{2\left(\begin{matrix}K\\H\end{matrix}\Big\}\Theta\right)} \quad + \quad \underset{\text{Zinc.}}{Zn} \quad = \quad \underset{\text{Zincate of potassa.}}{\begin{matrix}Zn\\K_2\end{matrix}\Big\}\Theta_2} \quad + \quad \underset{\text{Hydrogen.}}{\begin{matrix}H\\H\end{matrix}\Big\}}$$

As a diatomic metal, zinc combines with two atoms of chlorine, bromine, and iodine, giving a chloride $Zn\left\{\begin{matrix}Cl\\Cl\end{matrix}\right.$, a bromide $Zn\left\{\begin{matrix}Br\\Br\end{matrix}\right.$, and an iodide $Zn\left\{\begin{matrix}I\\I\end{matrix}\right.$. It forms besides with oxygen a protoxide $Zn\,\Theta$, and a binoxide $Zn\,\Theta_2$. To the protoxide corresponds a hydrate $\left.\begin{matrix}Zn\\H_2\end{matrix}\right\}\Theta_2$, which furnishes a series of salts by the substitution of the radical acids for the typical hydrogen it contains. With sulphur, zinc forms but one combination, namely, a monosulphide $Zn\,S$, which, under the name of blende, is the most abundant of its ores. The combinations of zinc with the monatomic metalloids have now to be considered.

Chloride of Zinc, $Zn\begin{cases}Cl\\Cl\end{cases}$.—Chloride of zinc may be obtained by heating zinc in a current of chlorine. The metal burns in this case, and is converted into chloride. But this chloride may be obtained much more rapidly and cheaply by dissolving zinc in hydrochloric acid.

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Hydrochloric acid.}}{2\left(\begin{matrix}H\\Cl\end{matrix}\right\}\Bigg)} = \underset{\text{Chloride of zinc.}}{Zn\begin{cases}Cl\\Cl\end{cases}} + \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}}$$

When the metal is dissolved, the solution is filtered to remove the impurities that do not dissolve, and afterwards evaporated. As soon as evaporation is complete, the mass is fused and run upon a clean stone, and immediately after solidification pounded and placed in a well-stopped bottle. If it were allowed to cool while exposed to the air, it would become moist on the surface. To the older chemists this substance was known as butter of zinc. If instead of completely evaporating the solution the operation be stopped when the liquor has become very concentrated, the chloride will be deposited by the cooling of the solution in hydrated crystals.

Chloride of zinc is of a greyish colour; it fuses at about 482°, and at 752° it begins to vapourize. It is an extremely diliquescent substance. It evolves much heat on dissolving in water, and its avidity for this liquid is such that it destroys the tissues of the body by taking up the water which they contain. For this reason it is often employed in medicine as a caustic. Alcohol also dissolves chloride of zinc. If such a solution be heated the alcohol will be dehydrated, and according to the proportion of chloride employed, there will be produced ethylene Θ_2H_4, or ether $\Theta_4H_{10}\Theta$.

$$\underset{\text{Alcohol.}}{\Theta_2H_6\Theta} = \underset{\text{Water.}}{H_2\Theta} + \underset{\text{Ethylene.}}{\Theta_2H_4}$$

$$\underset{\text{Alcohol.}}{2\,\Theta_2H_6\Theta} = \underset{\text{Water.}}{H_2\Theta} + \underset{\text{Ether.}}{\Theta_4H_{10}\Theta}$$

Bromide of Zinc, $Zn\begin{cases}Br\\Br\end{cases}$.—The bromide is obtained in the same way as the chloride, and it possesses similar properties.

Iodide of Zinc, $Zn\begin{cases}I\\I\end{cases}$.—This substance is prepared by pounding iodine and zinc dust in water; it is of a white colour and is soluble in water. Iodide of zinc is of very little importance; according to Bouchardat it might be employed in medicine in preference to the iodide of lead.

The combinations of zinc with the diatomic metalloids serve some important uses, and offer several points of interest.

Protoxide of Zinc, $Zn\,\Theta$.—For industrial purposes, some of which we have already alluded to, the protoxide of zinc is prepared directly by the combustion of the metal. This is effected by heating the zinc till it gives off vapours, and then setting it on fire; the smoke caused by the combustion is carried by a current of air through a series of chambers where the oxide is deposited. The oxide of zinc is also prepared by heating the hydrate of this metal, by calcining the nitrate or the carbonate, and by heating the bisulphite obtained by the action of sulphurous anhydride upon blende pulverized and in suspension in water. At ordinary temperatures this oxide is white; it becomes yellow when heated, but resumes its original colour on cooling. When obtained by the calcination of the metal, it is light and has a woolly appearance; if prepared from the bisulphite, it has a spongy appearance, but is equally light; but when obtained by calcining the nitrate, it is pulverulent and heavy.

The oxide of zinc is absolutely fixed; water dissolves only $\frac{1}{100000}$ of it, but this is sufficient to be sensible to litmus paper. It is a basic anhydride, making the double decomposition with the acids, and gives well-defined salts, isomorphous with those of magnesium.

Hydrate of Zinc, $\left.\begin{matrix}Zn\\H_2\end{matrix}\right\}\Theta_2$.—If an alkaline solution be poured into the solution of a salt of zinc, a precipitate is formed which, when collected upon a filter and well washed, constitutes the hydrate of zinc. This hydrate loses a molecule of water under the influence of heat, and leaves a residue of anhydrous oxide of zinc.

Hydrate of zinc produces the double decomposition with the acids, and gives salts which are due to the substitution of the radicals of these salts for its typical hydrogen. It must be considered as a somewhat powerful base; yet in the presence of the very powerful bases, it may also exchange its hydrogen for a metal and give zincates; in such a case it plays the part of a weak acid.

$$1.\quad \underset{\text{Hydrate of zinc.}}{\left.\begin{matrix}Zn\\H_2\end{matrix}\right\}\Theta_2} + \underset{\text{Nitric acid.}}{2\left(\left.\begin{matrix}N\Theta_2\\H\end{matrix}\right\}\Theta\right)} = \underset{\text{Nitrate of zinc.}}{\left.\begin{matrix}Zn\\(N\Theta_2)^2\end{matrix}\right\}\Theta_2} + \underset{\text{Water.}}{2\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)}$$

$$2.\quad \underset{\text{Hydrate of zinc.}}{\left.\begin{matrix}Zn\\H_2\end{matrix}\right\}\Theta_2} + \underset{\text{Potassic hydrate.}}{2\left(\left.\begin{matrix}K\\H\end{matrix}\right\}\Theta\right)} = \underset{\text{Water.}}{2\left(\left.\begin{matrix}H\\H\end{matrix}\right\}\Theta\right)} + \underset{\text{Zincate of potassa.}}{\left.\begin{matrix}Zn\\K_2\end{matrix}\right\}\Theta_2}$$

Sulphate of Zinc, $\left.\begin{matrix}S\Theta_2\\Zn\end{matrix}\right\}\Theta_2$.—In the laboratory, sulphate of zinc is prepared by dissolving metallic zinc in dilute sulphuric acid.

$$\underset{\text{Zinc.}}{Zn} + \underset{\text{Sulphuric acid.}}{\left.\begin{matrix}S\Theta_2\\H_2\end{matrix}\right\}\Theta_2} = \underset{\text{Sulphate of zinc.}}{\left.\begin{matrix}S\Theta_2\\Zn\end{matrix}\right\}\Theta_2} + \underset{\text{Hydrogen.}}{\left.\begin{matrix}H\\H\end{matrix}\right\}}$$

The residues from the preparation of hydrogen are utilized for this purpose; these liquors need only to be filtered and crystallized.

For industrial purposes, it is prepared by roasting blende or natural sulphide of zinc; oxygen thus enters into combination with this substance and converts it into a sulphate. The mass is then treated by water, which dissolves the sulphate of zinc; it is afterwards decanted and crystallized.

$$\underset{\text{Sulphide of zinc.}}{\mathrm{Zn\,S}} \quad + \quad \underset{\text{Oxygen.}}{2\left(\begin{matrix}\Theta\\ \Theta\end{matrix}\Big\}\right)} \quad = \quad \underset{\text{Sulphate of zinc.}}{\left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{Zn}\end{matrix}\right\}\Theta_2}$$

To render it more easy of transport, this salt is fused in its water of crystallization and run into cakes.

Sulphate of zinc dissolves in two or three times its weight of water at ordinary temperatures. At these temperatures it crystallizes with 7 molecules of water of crystallization; it may also crystallize with different quantities of water when the conditions under which crystallization takes place are varied. In every case the crystals of sulphate of zinc are isomorphous with those of the sulphate of magnesium that contain the same quantity of water.

This sulphate combines with the alkaline sulphates, and gives double salts which crystallize with 6 molecules of water. The double salt of zinc and potassium corresponds to the formula

$$\left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{Zn}\end{matrix}\right\}\Theta_2, \quad \left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{K}_2\end{matrix}\right\}\Theta_2 \quad + \quad 6\ \text{aq.}$$

When heated to a high temperature, sulphate of zinc is decomposed, and leaves a residue of oxide of zinc.

Binoxide of Zinc, $\mathrm{Zn}\,\Theta_2$.—The binoxide is obtained by acting on the protoxide with oxygenated water.

$$\underset{\text{Protoxide of zinc.}}{\mathrm{Zn}\,\Theta} \quad + \quad \underset{\text{Oxygenated water.}}{\mathrm{H}_2\Theta_2} \quad = \quad \underset{\text{Water.}}{\mathrm{H}_2\Theta} \quad + \quad \underset{\text{Binoxide of zinc.}}{\mathrm{Zn}\,\Theta_2}$$

It is a very unstable substance.

Sulphide of Zinc, $\mathrm{Zn\,S}$.—Sulphide of zinc is found native, and, under the name of blende, constitutes, as we have seen, the principal ore zinc. It may be obtained artificially by precipitating a salt of zinc by means of the soluble sulphides.

$$\underset{\text{Sulphate of zinc.}}{\left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{Zn}\end{matrix}\right\}\Theta_2} \quad + \quad \underset{\text{Sulphide of potassium.}}{\left.\begin{matrix}\mathrm{K}\\ \mathrm{K}\end{matrix}\right\}\mathrm{S}} \quad = \quad \underset{\text{Sulphate of potassium.}}{\left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{K}_2\end{matrix}\right\}\Theta_2} \quad + \quad \underset{\text{Sulphide of zinc.}}{\mathrm{Zn\,S}}$$

When roasted, the sulphide of zinc is converted, according to the temperature, either into a sulphate or into sulphurous anhydride and oxide.

$$1. \quad \underset{\text{Sulphide of zinc.}}{\mathrm{Zn\,S}} \quad + \quad \underset{\text{Oxygen.}}{2\left(\begin{matrix}\Theta\\ \Theta\end{matrix}\Big\}\right)} \quad = \quad \underset{\text{Sulphate of zinc.}}{\left.\begin{matrix}\mathrm{S}\,\Theta_2\\ \mathrm{Zn}\end{matrix}\right\}\Theta_2}$$

$$2. \quad \underset{\text{Sulphide of zinc.}}{2\,\mathrm{Zn\,S}} \quad + \quad \underset{\text{Oxygen.}}{3\left(\begin{matrix}\Theta\\ \Theta\end{matrix}\Big\}\right)} \quad = \quad \underset{\text{Sulphurous anhydride.}}{2\,\mathrm{S}\,\Theta_2} \quad + \quad \underset{\text{Oxide of zinc.}}{2\,\mathrm{Zn}\,\Theta}$$

Sulphide of zinc dissolves in the acids with a liberation of hydrosulphuric acid.

$$\underset{\text{Sulphide of zinc.}}{\mathrm{Zn\,S}} \quad + \quad \underset{\text{Hydrochloric acid.}}{2\left(\begin{matrix}\mathrm{H}\\ \mathrm{Cl}\end{matrix}\Big\}\right)} \quad = \quad \underset{\text{Chloride of zinc.}}{\mathrm{Zn}\left\{\begin{matrix}\mathrm{Cl}\\ \mathrm{Cl}\end{matrix}\right.} \quad + \quad \underset{\text{Sulphuretted hydrogen.}}{\left.\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\right\}\mathrm{S}}$$

Carbonate of Zinc.—The carbonate of zinc is also found in nature, and is known as calamine. It is one of the ores of zinc; but, except in the metallurgy of zinc, it has not been applied to any purpose.

Reactions of the Salts of Zinc.—The characteristics of the salts of zinc are the following:—

1. Hydrosulphuric acid does not precipitate them, unless the salt is derived from a weak acid, such as acetic acid, in which case a white precipitate of sulphide of zinc is formed.

2. Both potassa and ammonia throw down from their solutions a white precipitate of hydrate of zinc, soluble in an excess of the reagent.

3. Sulphide of ammonium produces in them a white precipitate of sulphide of zinc, soluble in dilute hydrochloric acid.

4. The carbonates of potassium and sodium give with the salts of zinc a white precipitate of carbonate of zinc insoluble in an excess of the reagent.

5. The carbonate of ammonia acts in the same manner; but in this case the precipitate dissolves in an excess of the reagent.

Professor Miller sums up the characters of the salts of zinc as follow;—The salts of zinc are colourless; their solutions have an astringent metallic taste, and act rapidly as emetics. They are distinguished by giving no precipitate in acid solutions with sulphuretted hydrogen, but they yield a white hydrated sulphide of zinc with sulphide of ammonium.

INDEX.

THE END.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.